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Evaluation of an Extended Aeration Process for Skokomish Salmon Processing Wastewater Treatment

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The project evaluated (full-scale) an extended aeration biological treatment system on salmon processing wastewater. During the first years evaluation the detention time in the aeration basin averaged 17 days (range 3 to 49 days). This was due to the plant processing significantly less salmon than anticipated. The BOD removal averaged over 90 percent (effluent about 50 mg/l).

A smaller aeration tank and settling tank were designed and installed to evaluate shorter and more reasonable detention times. The detention time in this system ranged from 0.3 to 9.2 days and averaged 4.4 days. BOD removal averaged about 80 percent. The effluent BOD and SS concentrations averaged 128 and 86 mg/l, respectively.

The economic evaluation indicated the total treatment costs per kkg of large and small salmon processed were $5.76 and $9.55, respectively.

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EVALUATION OF AN EXTENDED AERATION PROCESS FOR SKOKOMISH SALMON PROCESSING WASTEWATER TREATMENT

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for

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Grant No. S-803911

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FOREWORD

When energy and material resources are extracted, processed, converted, and used the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report characterizes wastewater generated from a salmon processing plant and demonstrates the reliability of biological systems for salmon processing waste control. The results will also provide the engineering criteria for future design application for fish processing waste control.

For further information regarding this report contact the Food and Wood Products Branch, Industrial Pollution Control Division, Industrial Environmental Research Laboratory--Ci, Cincinnati, Ohio 45268.

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ABSTRACT

The Skokomish salmon processing plant consists of a fish preparation area, smokehouses, refrigeration/freezing capacity, and a retail outlet. An extended aeration system was constructed in April 1975, to treat wastewater from the processing plant, and a monitoring program was initiated in September 1975, to evaluate the performance of the wastewater treatment facility.

During the first year's data collection, the fish volume was drastically reduced due to smaller returns and changes in regulations. Although BOD removal efficiencies were high during this period, suspended solids (SS) removal efficiencies and other parameters were low. The original design criteria for hydraulic detention time in the aeration chamber and the overflow rate in the clarifier were one day and 0.096 liter/sec/m^2, respectively. However, during the testing program, hydraulic detention time in the aeration chamber was much longer than desired, ranging from 3 to 49 days with an average of 17 days. Also the overflow rate in the clarifier was too low, ranging from 1.809×10^{-3} to 2.98×10^{-2} liter/sec/m^2 with an average of 0.01 liter/sec/m^2. The food-to-microorganisms ratios (F/M) ranged from 0.01 to 0.14 with an average of 0.06. To test the effect of a shorter detention time and a higher overflow rate on treatment efficiencies, a pilot plant with smaller capacity aeration tank and clarifier system was installed alongside the existing system.

During the pilot plant operation, hydraulic detention time was reduced to a range of 0.3 to 9.2 days with an average of 4.4 days. Similarly, the overflow rate was operating at a range of 0.054 to 0.41 liter/sec/m^2 with an average of 0.165 liter/sec/m^2. The F/M ratio increased to a range of 0.037 to 0.86, averaging 0.27.

The BOD removal efficiencies were high prior to the pilot plant installation and remain unaffected with the reduced detention times. The pilot plant suspended solids removal efficiencies, as expected, ran from approximately 50% to more than 90% than those previously observed in the full scale system. The removal efficiencies of other constituents also followed this pattern.

The economics of the operation of the extended aeration treatment system were evaluated. The economic evaluation indicated that total treatment cost (based on ENR 3161 for July 1978) per kkg of large and small salmon processed were $5.76 and $9.55, respectively. These costs were based on the design criteria developed in this study.

This report was submitted in fulfillment of Grant S-803911 by Skokomish Indian Tribe under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers a period from August 1975 to August 1978; data collection was completed as of January 1978.

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ABBREVIATIONS

BOD_5; BOD	5-day 20°C Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
SS	Suspended Solids
VSS	Volatile Suspended Solids
TKN	Total Kjeldahl Nitrogen
Ortho-p	Ortho-phosphate
Total-p	Total-phosphate
DO	Dissolved Oxygen
F/M	Food to Microorganism Ratio
DT	Detention Time
TS	Total Solids
JTU	Jackson Turbidity Unit
Alk	Alkalinity
OR	Overflow Rate
EPA	Environmental Protection Agency
KCM	Kramer, Chin & Mayo, Inc.
Max.	Maximum
Min.	Minimum
SD	Standard Deviation
O&M	Operation and Maintenance
M^3/Hr	Cubic Meter Per Hour
Liter/Sec	Liter Per Second
Liter/Sec/M^2	Liter Per Second Per Square Meter of Area
kg/M^3/Day	Kilogram Per Cubic Meter Per Day
Liter/Day	Liter Per Day

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Especially appreciated are Mr. Frank Klobertanz's contributions, including the set-up, field monitoring and sampling, laboratory analysis, data reduction, and operation and maintenance of the treatment facilities throughout the entire study.

SECTION 1

INTRODUCTION

The Skokomish River supports a large Indian commercial fishery which enables tribal fishermen to supplement their income and food supply during the fishing season. Historically, tribal fishermen had no means of preserving their catch other than smoking and marketed most of their catch in the round to traveling fish buyers. This situation often resulted in a weak market position for the fishermen and a quality loss in the fish due to the often lengthy time lag between catching the fish and refrigerating and processing the fish. In 1973, the Skokomish Indian Tribe constructed a salmon processing plant to purchase, process and market Indian-caught salmon.

The processing plant is operated as a tribal enterprise and its objectives are to provide increased income and employment opportunities to the Skokomish community and to raise the value of the fish harvest through prompt refrigeration and processing. The plant, designed by Bosworth and Carroll, consists of a fish-preparation area, smokehouses, refrigeration and freezing capacity, and a retail outlet. The plant markets fresh, fresh-frozen, and smoked-fish products. Freezing capacity allows the plant to smoke fish continuously throughout the year. The location and layout of the salmon processing plant are depicted in Figures 1 and 2, respectively. The plant is capable of processing 268 kg/hr of yearling salmon and 909 kg/hr of large salmon.

Presently, fish are hand-butchered at the plant. This increases blood and solids in the waste flow and imposes a higher loading on the wastewater treatment facility.

To comply with regulatory requirements, the wastewater treatment facility was constructed in conjunction with the processing plant in April 1975, and a water quality monitoring program was initiated in September 1975, to evaluate its performance. The treatment facility consists of an extended aeration system and two identical aerobic polishing ponds. The rationale used for the design of the treatment facility was based on literature review and characteristics of the waste as determined by daily grab samples.

The literature review was limited since very little has been published on the characteristics of salmon processing wastes. The objectives of this study were to determine the technical and economic feasibilities of treating salmon processing wastewater using the extended aeration treatment process and to develop more reliable design criteria.

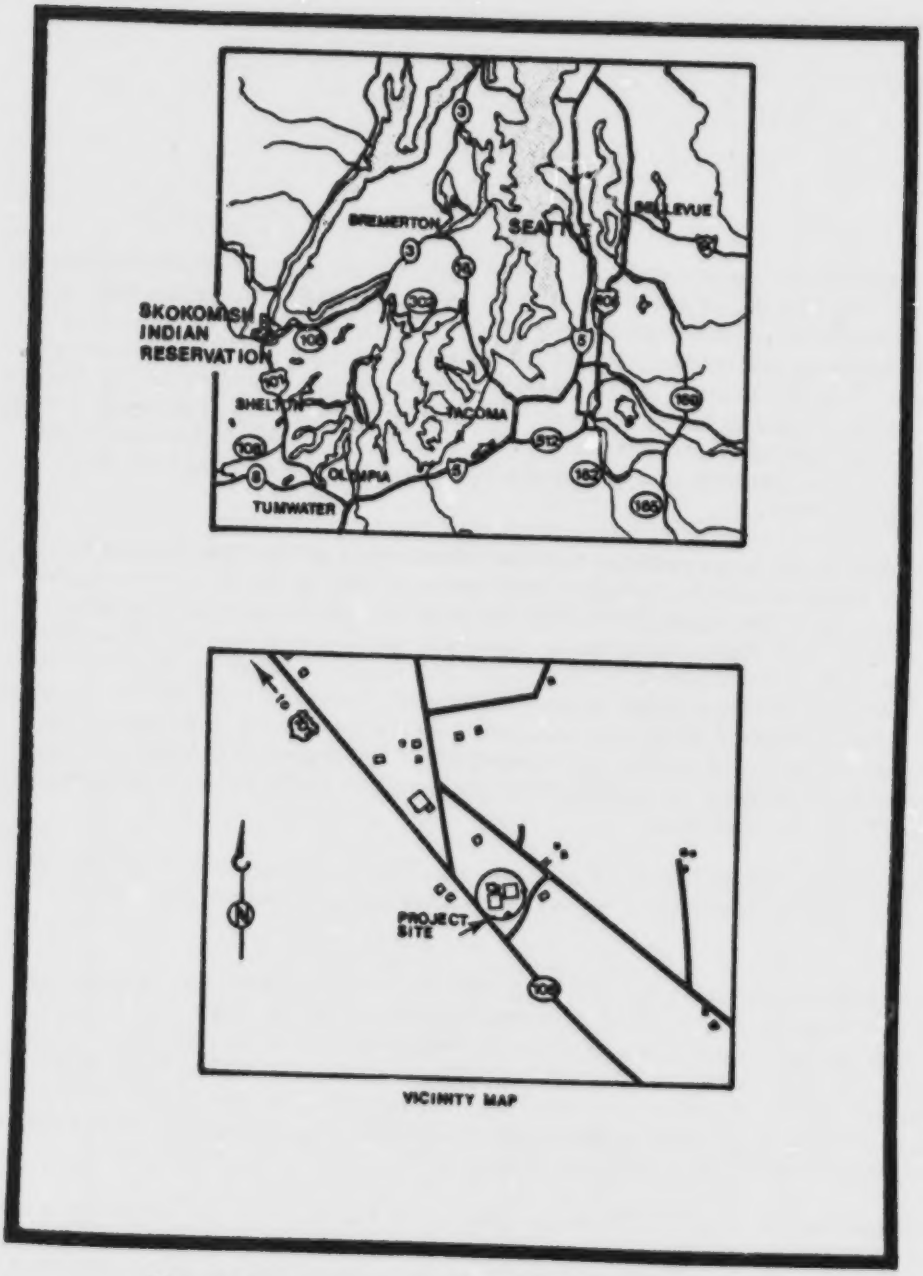

Figure 1. Location and vicinity maps
Skokomish Processing Plant
Shelton, Washington.

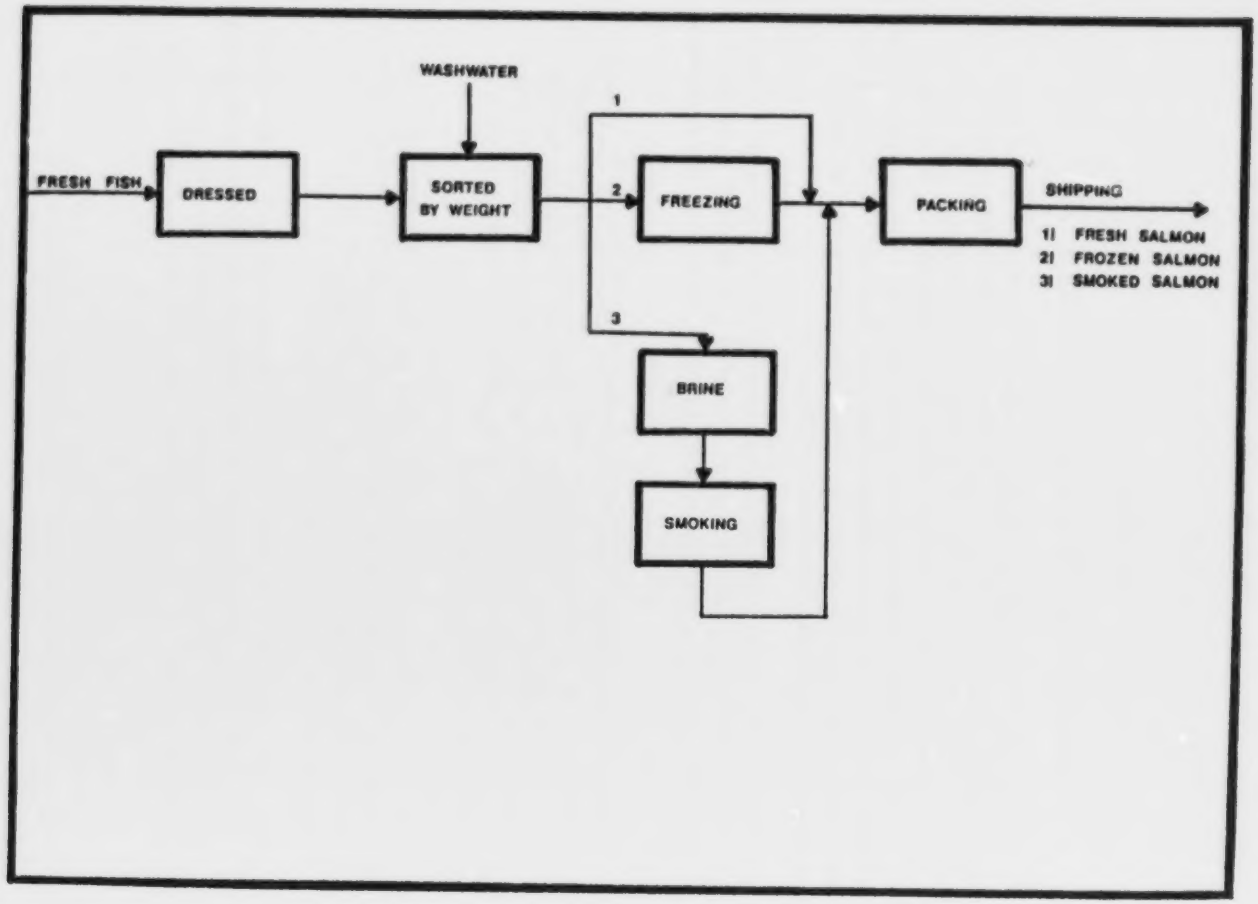

Figure 2. Process layout of Skokomish Salmon Processing Plant Shelton, Washington

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Wastewater characteristics for hand butchered salmon processing showed that small salmon processing generated more wastewater flow and higher pollutant contents per kkg of fish processed than did large salmon processing. It should be noted that raw wastewater was screened before being sampled for analyses. Wastewater flows and pollutant concentrations were highly variable in both cases. Pollutant, in terms of kg/kkg of fish processed, from the Skokomish plant was similar for large fish processing, but generally higher for small fish processing than for others surveyed in the Northwest and Alaska. (2)

During 1975 and early 1976, unexpected low flow resulted in long detention times and overaeration in the full-scale plant. To test the effect of shorter detention times on treatment efficiencies, a pilot plant was installed alongside the full-scale plant.

During full-scale plant operation, removal efficiencies of BOD, COD, SS, grease and oil, and ammonia for small fish processing were similar to those for large salmon processing. Higher removal efficiencies for nitrogen and lower removal efficiencies for phosphorus during large fish processing were the result of longer detention times and overaeration, which may have caused some denitrification and phosphorus release in the aeration chamber.

Pilot plant removal efficiencies were similar to those of the full-scale plant for BOD, COD, TKN and ammonia, but higher for solids, grease and oil and phosphorus. Higher pilot plant removal efficiencies for SS, oil and grease and phosphate were the results of shorter detention time and proper overflow rate.

Both 1) artificial feeding with fish food and 2) no feeding (wherein the organisms in the aeration tank were endogenously respirating) were studied during long periods of processing plant shutdown. The responsiveness of the system to take onset of normal loading caused by the resumption of processing activites was adequate in both cases.

Typical wastewater characteristics were determined and are summarized below:

Criteria	Large Salmon Processing	Small Salmon Processing
Wastewater flow (liter/kkg)	8,708	14,630
BOD loading (kg/kkg)	5.5	11.5
SS loading (kg/kkg)	2.5	5.5
Grease & Oil loading (kg/kkg)	5.2	8.2

Also developed were design criteria for the extended aeration system. Only the results from pilot plant study were used for the development of design criteria. The food-to-microorganism (F/M) ratio of about 0.25 at an average MLSS of 2,500 mg/l and a detention time of about 1.5 days were found to yield excellent treatment efficiencies. The dissolved oxygen content in the aeration chamber should be equal to or greater than 2.0 ppm. The minimum overflow rate in the clarifier was found to be about 0.062 liter/sec./m^2.

The effluent characteristics during the pilot plant study are summarized as follows:

Parameters	Average	95% Probability $\leq$
BOD (kg/kkg)	0.65	0.86
SS (kg/kkg)	0.32	0.60
Grease and oil (kg/kkg)	0.25	0.58

Based on comparison of suspended solids concentration increases, the filterability of sludge of the extended aeration system was found to be 20% less than that obtained from conventional activated sludge process while treating domestic wastewater.

An evaluation of the economics of the operation of the extended aeration treatment system indicated that total treatment cost (based on ENR 3161 for July 1978)per kkg of large and small salmon processed were $5.76 and $9.55, respectively. These costs were based on the design criteria developed in this study.

SECTION 3

CHARACTERISTICS AND TREATABILITY OF SALMON PROCESSING WASTES

Only the wastewater generated at a fresh-frozen salmon processing plant is discussed here because the Skokomish salmon processing plant does not include the canning process. The fresh-frozen salmon process is essentially the same throughout the industry. The only major factors affecting the waste characteristics are the geographic location and the size of the plant. Generally, the processing of Pacific salmon as a fresh or frozen commodity is considered to have smaller waste loads and waste flows than the canning segment of the salmon industry.[2]

Very little has been published about the characteristics of waste generated by salmon processing. Possibly the most reliable data for salmon-processing waste was provided by a seafood-waste survey[2] of six plants in three areas of Alaska and one area of the Northwest. Table 1 lists summary statistics of the waste loads from all hand-butchered salmon processes studied during this EPA sponsored survey. These results could be used to determine the typical raw-waste loadings resulting from fresh-frozen or hand-butchered salmon canning processes in both Alaska and the West Coast when characteristics of the particular wastewater of interest are not known.

At the time of the EPA study, biological treatment of seafood processing wastes had not been practiced fully in U.S. seafood plants except at pilot scale in a blue crab processing plant in Maryland and at full-scale in two shrimp processing plants in Florida.[2] The success of these systems plus the results of effluent characterization studies indicate that sufficient nutrients are available in most seafood wastewaters for aerobic biological treatment.

As early as 1968, a Federal Water Quality Control Administration report suggested that seafood wastewater can be treated by domestic sewage-treatment methods, with some allowance for increased waste strength.[9] In the EPA survey report of 1970,[10] the need for testing and identifying optimum operational conditions was stressed.

In a report issued in 1972, Riddle, et al,[3] studied the efficiency of biological treatment of smelt and perch wastewater. He found a 90% removal of total BOD_5 after 10 days of aeration, and 90% removal of soluble BOD_5 after 2 days aeration in a batch reactor. Tests in a continuous reactor showed that maximum BOD_5 removal (80% soluble and 45% total) could be achieved with a 7.5-hour detention time, sludge recycling and a 3-day sludge age, or a 5-day detention time with no sludge recycling.

TABLE 1
HAND-BUTCHERED SALMON PROCESS SUMMARY*

Parameter	Mean	Std. Dev.	5% Min.	95% Max.
Production, kkg/hr	1.94	0.99	0.67	3.98
Process Time, hr/day	6.34	1.80	3.67	8.98
Flow, l/sec	2.15	1.09	0.754	4.39
(gal/min)	34.1	17.2	11.9	77.5
Flow Ratio, l/kkg	5,040	3,100	1,410	13,000
(gal/ton)	1,210	743	338	3,120
Sett. Solids, ml/l	1.02	1.19	0.109	4.18
Ratio, l/kkg	5.15	5.99	0.547	20.5
Scr. Solids, mg/l	193	155	37.5	600
Ratio, kg/kkg	0.971	0.782	0.189	3.12
Susp. Solids, mg/l	236	185	47.6	722
Ratio, kg/kkg	1.19	0.933	0.240	3.54
5-Day BOD, mg/l	493	179	233	923
Ratio, kg/kkg	2.48	0.900	1.17	4.35
COD, mg/l	1,070	601	332	2,600
Ratio, kg/kkg	5.36	3.03	1.67	13.1
Grease/Oil, mg/l	341	628	15.0	1,770
Ratio, kg/kkg	1.72	3.16	0.076	8.39
Organic-N, mg/l	80.9	40.0	29.0	181
Ratio, kg/kkg	0.407	0.202	0.146	0.314
Ammonia-N, mg/l	2.12	0.794	0.979	4.14
Ratio, kg/kkg	0.011	0.004	0.005	0.120
pH	6.73	0.318	6.25	7.13
Temp., degrees C	13.2	2.51	9.19	15.7

*Summary from plants CSN5, CS6M, FS1, FS2, FS3, FS4, as presented in Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Canned and Preserved Fish and Seafood Processing Industry. EPA. September 1975.

In a later study, Robbins[10] reported that an activated-sludge plant in Japan has been designed especially for fish-waste treatment. The wastewater flow is approximately 11.88 liter/sec, and the 5-day BOD concentration ranged from 1,000 to 1,900 mg/l. The results of pilot-plant studies using a 10-hour aeration time, and the organic and hydraulic loadings, are listed in Table 2. Bulking occurred when the organic loading rate exceeded 4.96 kg/m^3/day.

The EPA effluent limitations guidelines for West Coast hand-butchered salmon processing plants are presented in Table 3.

TABLE 2
ACTIVATED SLUDGE PLANT RESULTS
FISH PROCESSING WASTES (10)

Parameter	Raw Waste	BOD Loading kg/m^3/day)			
		1.2	2.24	3.36	4.16
BOD_5 (mg/l)	1,000	5	10	13	27
% Removal	-	99.5	99.0	98.7	97.3

TABLE 3
EPA EFFLUENT LIMITATIONS GUIDELINES FOR
SALMON PROCESSING PLANTS*(2)

Parameter	Daily Max. (kg/kkg)	Maximum-30 Day Average (kg/kkg)
5-Day BOD (kg/kkg)	--	--
Total Suspended Solids (kg/kkg)	1.7	1.4
Grease and Oil (kg/kkg)	0.2	0.17

*Only for West Coast hand-butchered salmon, based on July 1, 1977 Effluent Limitations.

SECTION 4

SKOKOMISH WASTEWATER TREATMENT SYSTEM

The Skokomish processing plant's extended aeration treatment system, hereafter called the full-scale plant, was designed by Kramer, Chin & Mayo, Inc. The design was based on expected loadings from projected production of 909 kg/hr for large salmon and 268 kg/hr for yearling salmon. It was also projected by the Skokomish tribe that the processing plant would eventually double in capacity. Table 4 summarizes the actual production schedule since the project's initiation. The peak production period was July through October rather than September through January, as projected. In fact, in 1976 and 1977, no fish were available for processing in January. The bulk of the fish processed during February through July were yearling salmon from a private fish supplier. The large salmon processed were generally those caught by members of the tribe.

Design of the treatment facility was based on the projected production, literature review (Table 1) and daily grab samples for the determination of wastewater characteristics. The literature review was limited since very little has been published about the characteristics of salmon processing waste. Thus, the reliability of biological system for treating salmon processing waste was subject to verification and substantiation. Table 5 summarizes the design criteria, and Figure 3 presents a flow diagram of the treatment facility.

The projected volumes of incoming fish to process was not realized.

This decrease in operations resulted in lower flows and longer retention times in the treatment facility than expected. A smaller scale extended aeration system was constructed in September 1976, (hereafter called the pilot plant) to test lower retention times and higher loadings. Table 6 summarizes the design criteria for the pilot plant, and Figure 4 shows a diagram of the facility.

TABLE 4
SALMON PRODUCTION SCHEDULES
FROM SEPTEMBER 1975 THROUGH FEBRUARY 1977

Month		Monthly Total (kg)	Daily Average* (kg)	Size**
1975	September	35,628***	1,619	Large
	October	34,178	1,554	Large
	November	13,575	617	Large
	December	3,918	178	Large
1976	January	-0-	-0-	---
	February	22,636	1,029	Small
	March	29,350	1,334	Small
	April	-0-	-0-	Small
	May	17,432	792	Small
	June	15,486	704	Small
	July	27,223	1,237	Small
	August	68,340	3,106	Small/Large
	September	20,245***	1,841	Large
	October	42,807	1,946	Large
	November	10,249	466	Large
	December	12,750	580	Large
1977	January	-0-	-0-	---
	February	-0-	-0-	---

*Based on 22 working days per month and one shift per day.
**Large fish averages approximately 4.5 kg; small fish averaged approximately 0.3 kg.
***Value for last half of September.

TABLE 5
DESIGN CRITERIA FOR SKOKOMISH FULL-SCALE WASTEWATER TREATMENT PLANT

Waste Characteristics

Source = Process water, no sanitary waste
Minimum Flow = 0 liter/sec.
Maximum Flow = 0.87 liter/sec.
Peak Flow = 1.13 liter/sec.
Daily Flow Variation = Continuous over approximately 18 hour
Average BOD Concentration = 500 mg/l
Average Suspended Solids Concentration = 100 mg/l
Maximum BOD Loading = 36 kg/day

Extended Aeration System

Aeration Tank:
Volume = 76,000 liters
Detention Time at Maximum Flow = 24 hours
Maximum Oxygenation Available = 109 kg O_2/day
Maximum Loading = 0.48 kg BOD/m^3/day

Clarifier:
Volume = 11,400 liters
Detention Time at Maximum Flow = 2.7 hours
Surface Area = 9.1 m^2
Overflow Rate at Maximum Flow = 0.096 liter/sec./m^2

Polishing Ponds

Surface Area = 0.15 ha
Loading at Maximum Flow = 24.1 kg BOD/ha/day
Volume = 1,383 m^3
Detention Time at Maximum Flow = 18 days

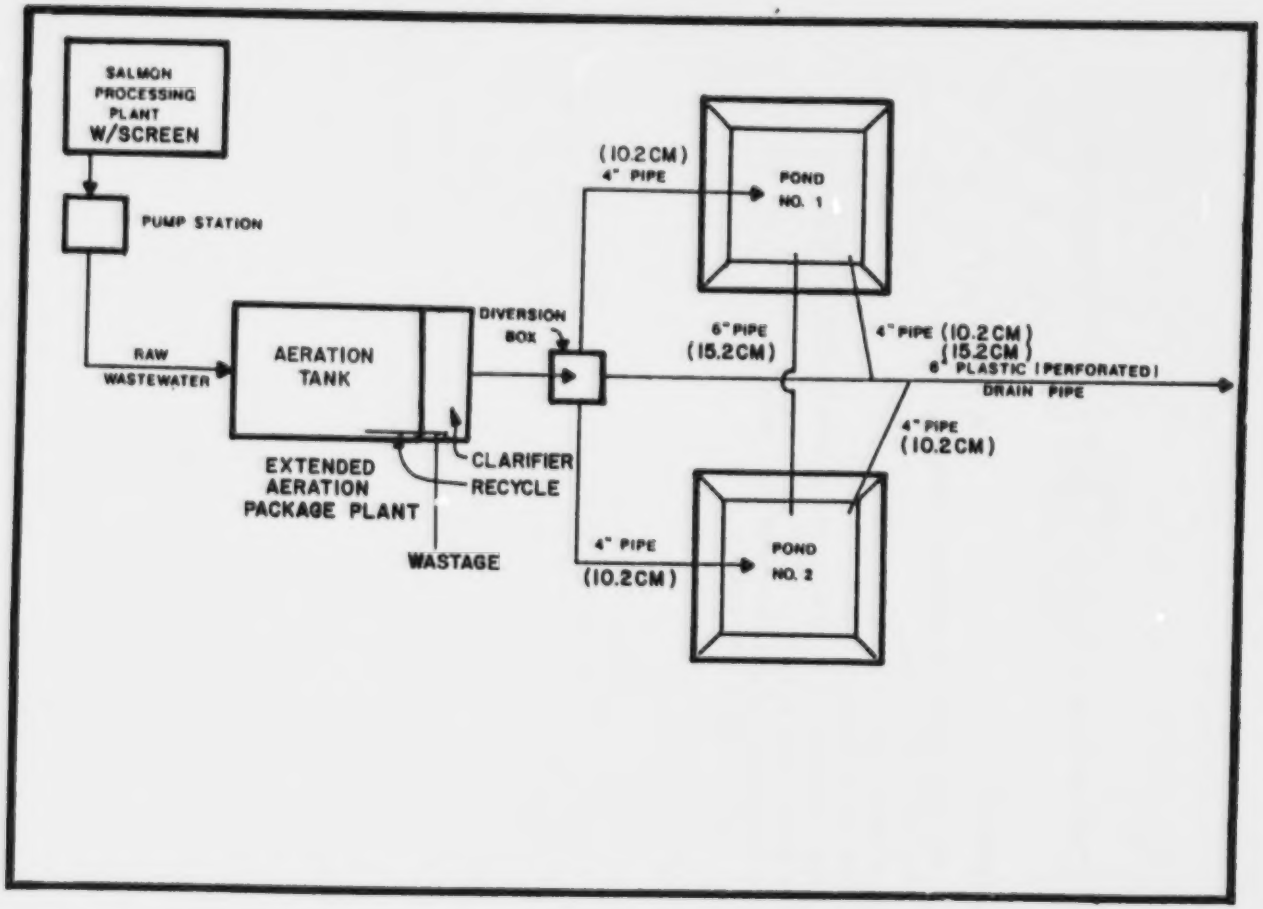

Figure 3. Flow scheme of the waste treatment system Skokomish Processing Plant Shelton, Washington

TABLE 6
DESIGN CRITERIA FOR SKOKOMISH PILOT TREATMENT PLANT

Aeration Chamber

1) Dimensions:
   Diameter: 4.6m
   Depth : 1.2m
   Total volume = 17.1m^3 @ 1.1m water depth
   (Two chambers @ 8.55m^3 each)

2) Air supply
   No. 22 Blower ; 23.8 cfm
   @ 210 gram/cm^2

3) Chamber divider, plastic sheeting siliconed in place with baffles to equalize head.

Clarifier

Number:	2
Volume:	513 liters each
Surface area:	0.58 m^2 each
Compressor for sludge return air lift pump:	4.3 m^3/hr. @ 1750 gram/cm^2

Operation conditions

Aeration Chamber -
Detention time 18 hr. – 120 hr. (if flow>0.098 liter/sec. dual system was in operation)

Clarifier -
Detention time: 1.1 hr. – 7.9 hr.
Overflow rate: 0.0031 - 0.23 liter/sec./m^2

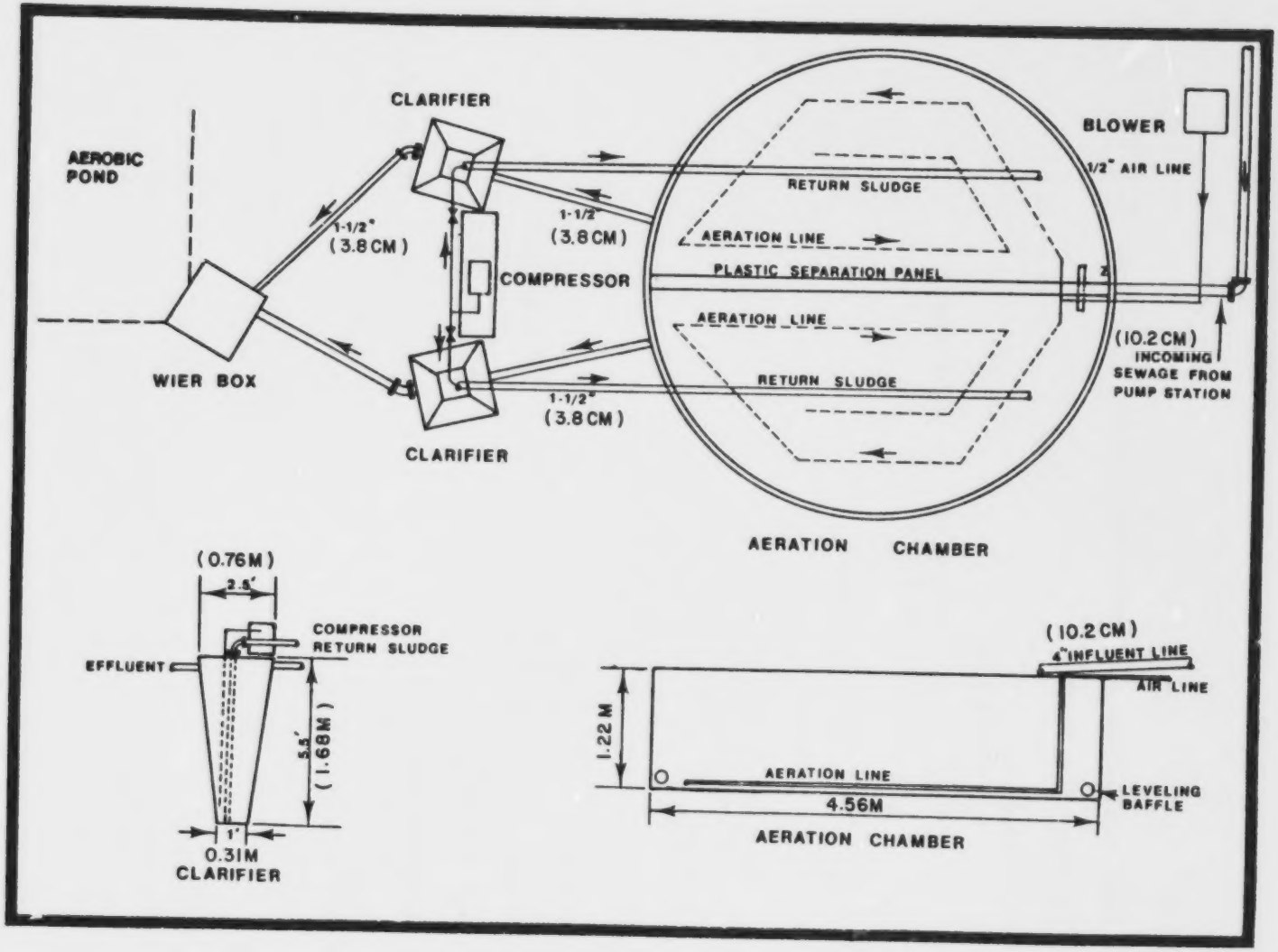

Figure 4. Skokomish Pilot Treatment Plant

SECTION 5

WATER QUALITY MONITORING PROGRAM

TEST SCHEMES

The test scheme for both full scale and pilot plant is shown in Figure 5. Because of low flow through the full-scale treatment system and the high permeability of the soils in the aerobic pond, the full-scale monitoring program was focused on the extended aeration treatment system.

For the extended aeration system, two major parameters, dissolved oxygen (DO) content and food-to-microorganism (F/M) ratio, were controlled during the study period. The DO content was varied by adjusting either impeller immersion and/or aeration time. The F/M ratio (BOD/MLVSS) was varied by adjusting MLVSS (Mixed Liquor Volatile Suspended Solids) concentration, which was controlled by regulating the sludge recycling rate and the quantity of sludge wasted.

SAMPLING

Four sampling stations for the test scheme are shown in Figure 5. The location of each sampling station is described as follows:

Sampling Stations	Location
a	Incoming raw wastewater
b	Aeration tank
c	Return sludge and excess sludge pipe
d	Effluent from the extended aeration process

It should be noted that raw wastewater generated in the processing plant passed through a screen and discharged into the pump station. Then, the screened raw wastewater was pumped to the extended aeration treatment system.

Both grab and composite samples collected in the field were preserved in accordance with Methods for Chemical Analysis of Water and Wastes.[5] Table 7 summarizes the schedule for each sampling day and analysis. Throughout most of the study, sampling took place 3 days every two weeks.

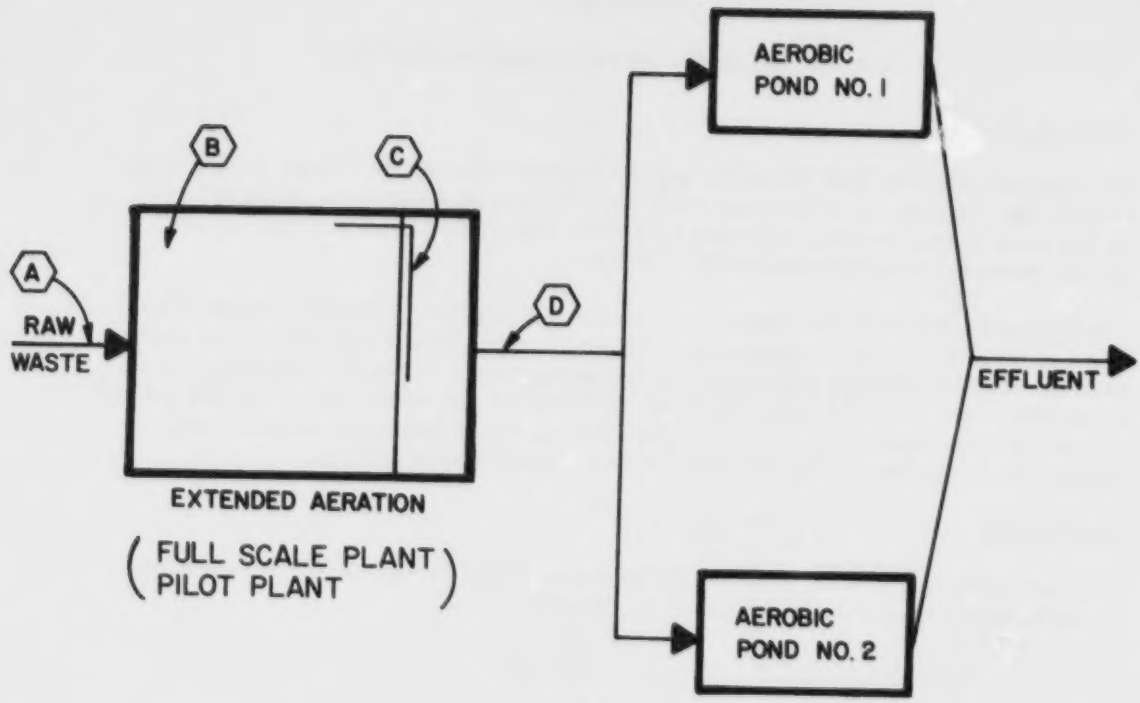

Figure 5. Test Scheme

TABLE 7
SCHEDULE FOR EACH SAMPLING DAY

Sampling Station	Sampling Frequency	Tests
a	Grab Samples/2 hour	Flow, Temp, pH, DO
	Eight-hour Composite Sample	BOD, COD, SS, VSS, TS, Grease/Oil*, TKN, Ammonia, Ortho-P, Total-P, Alkalinity, Turbidity
b	One Grab Sample Daily	MLSS, MLVSS, DO, Alk., pH, Temp., Oxygen Uptake Test
c	One Grab Sample Daily	SS, VSS, Sludge Filterability Test
d	Same as (a)	Same as (a) (Except flow measurement is not necessary)

*One grab sample per sampling day.

TESTING

All chemical and biological tests were conducted in accordance with Standard Methods.[4] Field tests included flow measurement, pH, DO, temperature, and oxygen uptake. Laboratory tests conducted in the KCM Laboratory were BOD, COD, SS, VSS, TS, grease and oil, TKN, ammonia, alkalinity, turbidity, ortho-P, total-P, MLSS, MLVSS, SVI, and sludge filterability.

The flow entering the treatment system was computed based on pumping duration and rate. The measurement of SVI (Sludge Volume Index) was conducted in accordance with Standard Methods.[4] The oxygen uptake test was conducted in the field by using YSI DO probe. The DO of MLSS was measured at 0 and 60 minutes. The oxygen uptake rate was computed by dividing the decrease in oxygen by the elapsed time. The sludge filterability test was conducted in the laboratory. The sludge was filtered under a pressure of 1470 gram/cm^2 and suspended solid concentrations were measured at different time intervals.

Due to difficulties in obtaining fish to process during parts of the study (see Table 4), the monitoring program was extended and completed in January 1978.

SECTION 6

RESULTS AND DISCUSSION

GENERAL

At the project initiation the aeration chamber of the full-scale plant was seeded with 3,800 liters of 4,500 mg/l S.S. return activated sludge from Renton Treatment plant, Renton, Washington. Water meters were installed in the processing plant for continuous recording of water consumption during fish processing. The records of water consumption were to be used to establish a relationship between the water consumption and wastewater generated during fish processing. Wastewater from fish processing was pumped to the treatment facility after screening. It should be noted that the extended aeration system is intended to treat only wastes from fish processing. Sanitary wastes were conveyed to a septic tank for treatment. Based on pumping duration and rate, the flow entering the extended aeration system was computed. A weir box was installed at the aerobic pond to record the flow rate of effluent from the extended aeration treatment system.

Most of the wastes entering the treatment system were generaged from processing of small yearling salmon and large salmon. "Small salmon" herein refers to an average weight of 0.3 kg per fish while "large salmon" refers to an average weight of 4.5 kg per fish. When no processing wastewater was generated, the treatment systems were maintained by 1) feeding approximately 4.3 kg of Purina Trout Chow mixed in 2130 liters of water into the pump station during full scale plant operation, and 2) by endogenous respiration (without the addition of fish food) during pilot plant operation. On the average, duration of pumping fish food solution was about 4 hours. The relationship between fish processing activities and the operation of the extended aeration treatment system during the entire study is chronologically plotted in Figure 6. Monitoring results indicated that characteristics of the fish food mixture were comparable to those of salmon processing wastewaters.

WASTEWATER CHARACTERISTICS

Wastewater characteristics for large/small salmon processing and fish food addition are summarized in Table 8. Approximately 20 percent of the total weight of fish processed was wasted. The wastage was hauled away to a sanitary landfill for disposal. The water consumption for fish processing is approximately equal to the wastewater generated from fish processing. Thus, only wastewater flow is shown in Table 8. Comparison of the wastewater characteristics showed that wastewater flow and the weight of pollutants generated per kkg of fish processed for small salmon were greater than those for large salmon. As indicated by the standard deviations, the incoming wastewater in both cases was highly variable.

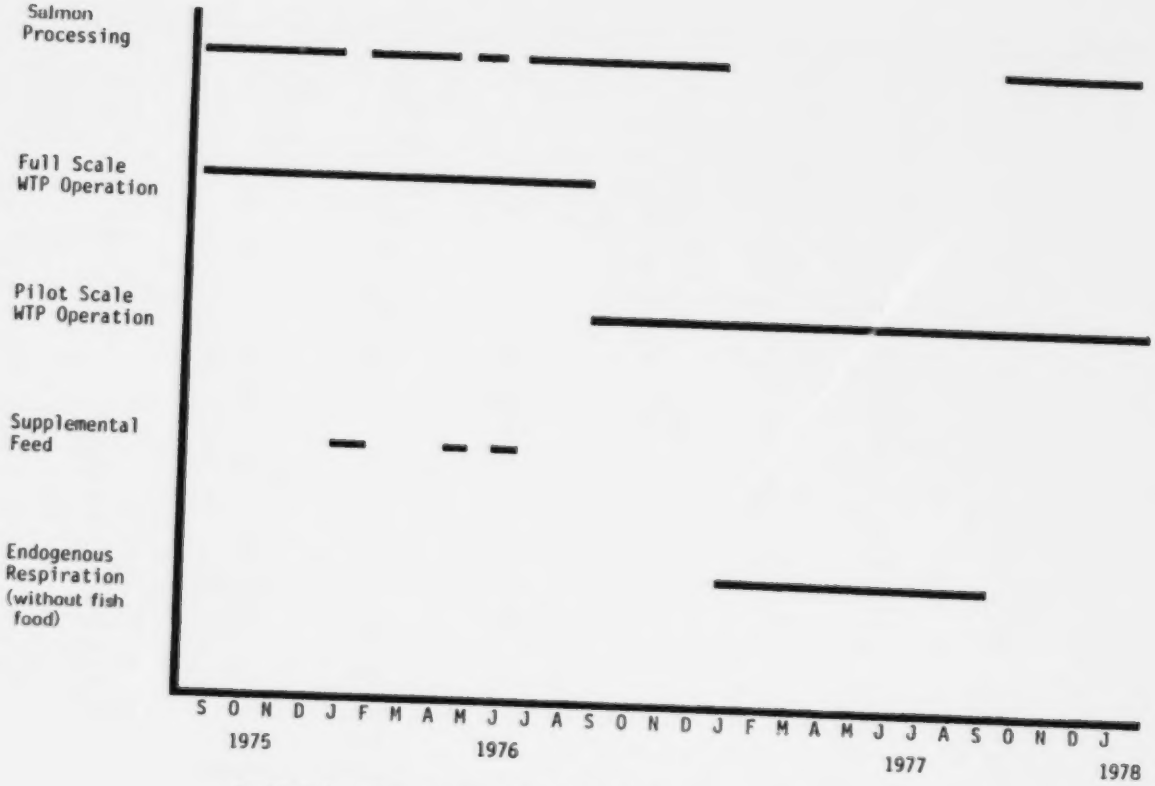
Salmon Processing
Full Scale WTP Operation
Pilot Scale WTP Operation
Supplemental Feed
Endogenous Respiration (without fish food)
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J
1975
1976
1977
1978

FIGURE 6 Chronological Plot for Fish Processing Activities and the Operation of the Extended Aeration Treatment System

TABLE 8
WASTEWATER CHARACTERISTICS FOR THE SKOKOMISH SALMON PROCESSING PLANT

Parameter	1975 & 1976 Full-Scale Plant, Large-Salmon, Average	1975 & 1976 Full-Scale Plant, Large-Salmon, Standard Deviation	1975 & 1976 Full-Scale Plant, Fish Food Addition, Average	1975 & 1976 Full-Scale Plant, Fish Food Addition, Standard Deviation	1976 & 1977 Pilot Plant, Small Salmon, Average	1976 & 1977 Pilot Plant, Small Salmon, Standard Deviation	1976 & 1977 Pilot Plant, Large Salmon, Average	1976 & 1977 Pilot Plant, Large Salmon, Standard Deviation
Flow, gpd	691	237	1,022	1,017	3,143	1,001	1,262	1,446
Process Time, hr/day	6.5	1.0	-	-	5.4	1.3	8.8	6.55
Fish Processed, lb/day	3,153	2,658	-	-	2,751	812	3,099	2,831
Processing Wastage, lb/day	747	614	-	-	570	170	756	600
Gallon of Wastewater per Ton of Fish Processed	723	599	-	-	2,366	764	501	504
Turbidity, JTU	100	49	91.5	324	60.8	44.2	116	61.4
pH	7.2	0.1	6.9	0.2	7.1	0.2	7.3	0.25
DO, mg/l	7.9	1.0	-	-	7.3	1.7	5.4	2.3
Temp., degrees F.	51.5	3.6	45	1.6	52.5	2.3	54.4	6.1
Alk., mg/l as $CaCO_3$	128	88	59	13.8	49	7	92.2	13
BOD (total), mg/l	687	445	400	56.8	665	273	1,053	830
BOD (total), lb/ton	3.26	2.50	-	-	10.36	5.29	5.34	4.51
COD (total), mg/l	2,057	1,120	688	131	902	398	1,386	941
COD (total), lb/ton	10.5	8.6	-	-	13.9	6.4	7.6	6.3
BOD/COD (total)	0.33	0.10	0.59	0.06	0.70	0.12	.67	.17
SS,mg/l	502	224	354	134	320	479	509	382
SS, lb/ton	2.5	1.4	-	-	4.4	3.3	3.2	3.4
VSS, mg/l	265	147	200	61	225	405	377	300
VSS, lb/ton	1.3	0.9	-	-	2.6	2.0	2.3	2.6
VSS/SS	0.541	0.175	0.65	0.36	0.703	0.192	0.73	0.13
TS, mg/l	1,638	861	525	219	1,029	650	1,197	624
TS, lb/ton	7.5	2.8	-	-	15.8	8.2	8.3	7.4
Grease and Oil, mg/l	283	142	199	203	859	372	382	289
Grease and Oil, lb/ton	1.5	0.9	-	-	4.3	2.2	3.4	4.3
TKN, Mg/l	207	197	99	10.6	73	50	37.6	28
TKN, lb/ton	0.86	0.49	-	-	1.08	0.78	0.6	1.27
H_4-N, mg/l	6.04	7.25	2.5	0.8	4.67	3.20	13.4	11.5
H_4-N, lb/ton	0.04	0.04	-	-	0.30	0.32	0.17	.21
Total-P, mg/l	0.26	0.16	1.5	0.4	0.56	0.35	1.46	1.19
Total-P, lb/ton	0.00020	0.00027	-	-	0.0085	0.0065	0.04	0.05
Ortho-P, mg/l	0.11	0.05	0.33	0.12	0.49	0.23	0.99	0.98
Ortho-P, lb/ton	0.0007	0.0007	-	-	0.0052	0.0036	0.02	0.01

NOTE: 1) 1 lb/ton = 0.5 kg/kkg

2) 1 lb/ton = Flow (gpd) x mg/l x $8.34 \times 10^{-6} \times \frac{2000}{\text{(Fish processed) lb/day}}$.

3) 1 gal/ton = 4.18 liter/kkg.

The wastewater characteristics for large salmon processing as influent to the pilot plant are also shown in Table 8. During the pilot plant study, no small salmon were processed. Wastewater entering the pilot plant was more concentrated than that resulting from previous large salmon processing. This can be explained by the following: the processing plant received returning adult Chinook, Chum and Coho salmon. Generally Chinook are the largest and Coho the smallest in size. The adult returns received in 1976 and 1977 contained a larger portion of the smaller fish than those received in 1975.

Comparison of Table 8 to Table 1 indicates that pollutant concentrations from the Skokomish processing plant were generally greater than for those surveyed. Weights of pollutant generated per kkg of fish processed were similar for large salmon processing, but higher for small salmon processing than those surveyed.

OPERATING CONDITIONS

Operating conditions for both full scale and pilot plants are summerized in Table 9. Because the projected numbers of fish were not realized, both hydraulic detention times and DO concentrations in the aeration chambers were higher than expected. However, the food to microorganism (F/M) ratios were within the range of 0.05 to 0.2 recommended for the extended aeration process. The higher flows resulting from small salmon processing reduced the detention time to seven days in the full-scale plant. The change-over to the pilot plant occurred coincident with a switch to processing large salmon, and the consequent reduction in flows resulted in a retention time of somewhat more than four days in the pilot plant aeration tank. In other words, the expected wastewater flow from small salmon processing was not realized during the pilot plant operation. In order to test retention times about one day, a solution of fish food was used to simulate the salmon processing wastewater. The fish food addition was proved to be comparable to salmon processing wastewater during full-scale plant operation, as shown in Table 10.

During the peak flow entering the pilot plant, it was noticed that more of MLSS was carried over the clarifier resulting in an effluent with poor quality. This gave an indication that the overflow rate in the clarifier during peak flow was higher than expected. No samples were taken when peak flow was evident.

The ratios of MLVSS to MLSS during the study were similar to that obtained from domestic wastewater treatment. It should be noted that the ratio of MLVSS to MLSS of full scale operation while receiving large salmon processing wastewater was only 58%. This lower ratio was due to low flow which subsequently resulted in longer detention time and higher DO content in the aeration chamber. In other words, a portion of MLVSS was digested in the aeration chamber.

The Sludge Volume Index (SVI) decreased when detention time decreased. This indicated that overaeration resulting from long detention time had adverse impact on the settleability of MLSS in the clarifiers.

TABLE 9
OPERATING CONDITIONS FOR THE EXTENDED AERATION FACILITIES

Parameter	1975 & 1976 Full-Scale Plant						1976 & 1977 Pilot Plant	
	Large-Salmon		Fish Food Addition		Small Salmon		Large Salmon	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Retention Time (days)	31	8	30	13	7	2	4.4	5.1
Processing Time (hrs/day)	6.5	1.0	-	-	5.4	1.3	7.8*	5.64*
pH	7.3	1.0	7.4	0.3	7.1	0.4	7.03	0.3
DO (mg/l)	8.3	1.4	9.7	1.4	5.7	1.5	2.4	1.5
SVI	151	24	97	47	129	28	126	36
F/M (1/day)	0.06	0.06	0.04	0.04	0.05	0.04	0.27	0.22
MLVSS (mg/l)	516	174	540	114	1,015	433	1,964	383
MLSS (mg/l)	978	218	1,306	93	2,240	666	2,485	613
MLVSS/MLSS Ratio	58%				69%		80%	
Overflow Rate (gal/processing period/square foot) gpd/ft^2 **	38	22	11	11	173	105	349	203*

*included hours during which flow was controlled to decrease retention time.

**1 gpd/ft^2 = 4.73 x 10^{-4} liter/sec/m^2.

TABLE 10
EXTENDED AERATION TREATMENT EFFICIENCIES FOR SALMON PROCESSING WASTEWATER

	1975 & 1976 Full-Scale Plant						1976 & 1977 Pilot Plant	
	Large-Salmon		Fish Food Addition		Small Salmon		Large Salmon	
Parameter	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
BOD, %	91	8	88	7	91	5	77.8	20.4
COD, %	88	5	85	6	82	14	77.1	17.7
SS, %	62	18	78	12	52	32	74.6	22.9
VSS, %	66	20	75	6	47	36	73.8	26.5
TS, %	45	19	54	10	46	36	51.7	19.7
Grease and Oil, %	69	19	61	16	55	20	72	20.9
TKN, %	83	16	92	0.5	46	31	73.9	21.6
NH_4-N, %	72	24	21	17	37	29	61.3	18.6
Total-P, %	28	3	N/A*	N/A*	58	43	40.9	22.7
Ortho-P, %	37	25	N/A*	N/A**	N/A**	N/A**	49.1*	24.2*

**N/A indicated that effluent concentrations were either greater than or equal to influent.
*Does not include negative data.

During the full-scale plant operation, the volumetric loading was 32 kg BOD_5/1,000 m^3 and 112 kg BOD_5/1,000 m^3 on the average for large and small salmon processing wastewater respectively. This was increased to 480 kg BOD_5/1,000 m^3 for the pilot plant.

The effects of various operating conditions, such as F/M, DO, detention time etc., on treatment efficiencies are further discussed in detail in Section VIII -Development of Design Criteria. Also included in Section VIII are the oxygen uptake characteristics for MLSS, and sludge dewaterability characteristics.

TREATMENT EFFICIENCIES

The extended aeration treatment efficiencies for salmon processing wastewater and fish food addition are summarized in Table 10. During the full-scale plant operation, comparison indicated that treatment efficiencies for fish food addition were comparable to those for salmon processing wastewater. During the pilot plant study, the extended aeration treatment facility received neither salmon processing wastewater nor fish food feeding for about 8 months (see Figure 6). The results shown in Table 10 indicated that the resumption of the operation was not significantly affected by this long period of shutdown. This demonstrated that when no salmon processing was available the responsiveness of the treatment system could be maintained without supplemental feeding.

Comparing large and small salmon processing wastewater at the full-scale plant, removal efficiencies for most parameters were not appreciably different except for nutrients. Ammonia and TKN removal efficiencies were twice as high for the large fish processing wastewater. This is probably due to the higher incoming concentrations (see Table 8) and longer detention times causing some denitrification. Conversely, the removal efficiencies of total phosphate are about 50 percent lower for large fish. This fact may have been due to over aeration which resulted from longer detention time, causing the release of phosphate in the aeration chamber.(7)

Comparing large fish processed at the full-scale and pilot plants, removal efficiencies for BOD, COD, TKN, and ammonia were similar. However, the removal efficiencies for solids, grease/oil and phosphate during the pilot plant operation increased dramatically. Reasons for the increase in phosphate removal are discussed above. Improvements in removal efficiencies for solids and grease/oil are probably due to higher incoming concentrations and shorter detention times. During full-scale plant operations effluent turbidity was approximately 30 percent higher even though the clarifier overflow rate was lower. A microscopic examination of MLSS indicated the presence of filamentous growth. It can be explained that the longer detention times at high DO concentrations favored filamentous growths in the full-scale plant. Apparently, filamentous microorganisms which have poor settling characteristics are able to slowly utilize the inert polysaccharide material produced by the bacteria, giving the filamentous forms a source of food that is unavailable to other bacteria.(8)

EFFLUENT CHARACTERISTICS

Effluent characteristics for both full-scale and pilot plants are summerized in Table 11. The effluent charcteristics during fish food addition are not shown since fish food addition was only one of the alternatives used to maintain the performance of the treatment system when no salmon processing wastewater is available. As indicated by the standard deviation, the effluent of extended aeration facilities was as variable as incoming wastewater. However, the removal efficiencies for each parameter were quite consistent, as shown in Table 10.

TABLE 11
EFFLUENT CHARACTERISTICS OF THE EXTENDED AERATION FACILITIES

Parameter	1975 & 1976 Full-Scale Plant				1976 & 1977 Pilot Plant	
	Large-Salmon		Small Salmon		Large Salmon	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Turbidity, JTU	28	22	13.4	6.1	29	23
pH	7.4	1.0	7.06	0.23	7.0	0.3
DO, mg/l	6.7	2.0	4.3	1.6	3.6	1.6
Temp., degrees F.	56	5.6	53.5	7.5	56	8
Alk., mg/l as $CaCO_3$	45.1	23.5	67.7	31.4	92	17.6
BOD (total), mg/l	50.4	43	43.4	26.6	128	93
BOD (total), lb/ton	0.25	0.18	0.88	0.57	1.3	3.1
COD (total), mg/l	206	88	94.7	35.4	208	180
COD (total), lb/ton	1.11	0.84	2.18	2.23	1.3	1.32
BOD/COD (total)	0.23	0.49	0.46	0.75	0.62	0.22
SS, mg/l	163	118	85	48.6	86	91.6
SS, lb/ton	0.77	0.46	2.02	2.6	0.64	1.05
VSS, mg/l	85	56	60.4	37.4	66	69
VSS, lb/ton	0.43	0.32	1.72	2.1	0.49	0.81
VSS/SS	0.52	0.47	0.71	0.77	0.77	0.75
TS, mg/l	1,030	499	532	230	511	143
TS, lb/ton	3.12	4.31	13.4	13.04	3.9	3.93
Grease and Oil, mg/l	72	44	79.2	31.4	71.7	48.2
Grease and Oil, lb/ton	0.41	0.43	1.64	1.1	0.5	0.49
TKN, mg/l	23.4	22.7	12.3	16.7	7.3	9.7
TKN, lb/ton	0.17	0.23	0.22	0.27	0.08	0.1
NH_4-N, mg/l	1.05	0.59	2.17	2.15	7.8	9.9
NH_4-N, lb/ton	0.01	0.01	0.05	0.04	0.11	0.19
Total-P, mg/l	0.43	0.76	0.49	0.36	0.7	0.5
Total-P, lb/ton	-	-	0.02	0.02	0.01	4.2×10^{-3}
Ortho-P, mg/l	0.1	0.04	0.42	0.67	0.3	0.23
Ortho-P, lb/ton	-	-	0.01	0.005	0.01	-

Note: 1) 1 lb/ton = Flow (gpd) x mg/l x 8.34×10^{-6} x $\frac{2000}{\text{fish processed lb/day}}$.

2) 1 lb/ton = 0.5 kg/kkg.

SECTION 7

DEVELOPMENT OF DESIGN CRITERIA

An important objective of the study was to utilize the results to develop engineering criteria for future design. The following discussion of the development of design criteria includes (1) the estimate of wastewater characteristics; (2) the effects of DO content, F/M ratio, detention time and overflow rate on the treatment efficiencies; (3) Estimate of treatment plant effluent characteristics; (4) relationship of oxygen uptake rates to F/M ratio, and (5) sludge filterability characteristics.

WASTEWATER CHARACTERISTICS

Wastewater characteristics for both large salmon and small salmon processing were discussed in Section VI and are summarized in Table 8. The wastewater was highly variable. To facilitate the development of design criteria, the wastewater characteristics in terms of flow, BOD, SS and Grease and Oil are plotted on probability paper. The probability herein refers to the percentage measurement equal to or less than the stated class mean of the measured parameter.

Figure 7 illustrates the probability of wastewater generated per kkg of large salmon processed. It can be seen in Figure 7 that 95% of the time the wastewater generated was 8,780 liter/kkg or less during large salmon processing.

Figure 8 indicates that 95% of the time the BOD loading was about 5.5 kg/kkg or less during large salmon processing. Figure 9 shows that 95% of the time the SS loading was about 2.5 kg/kkg or less for large salmon processing wastewater. Figure 10 reveals that 95% of the time the grease and oil loading was 5.2 kg/kkg or less for large salmon processing wastewater.

Similarly, the probability of flow, BOD, SS and grease and oil for small salmon processing wastewater are illustrated in Figures 11, 12, 13, and 14, respectively. The design criteria for wastewater characteristics in terms of flow, BOD, SS and grease and oil using 95% probability are summarized in Table 12.

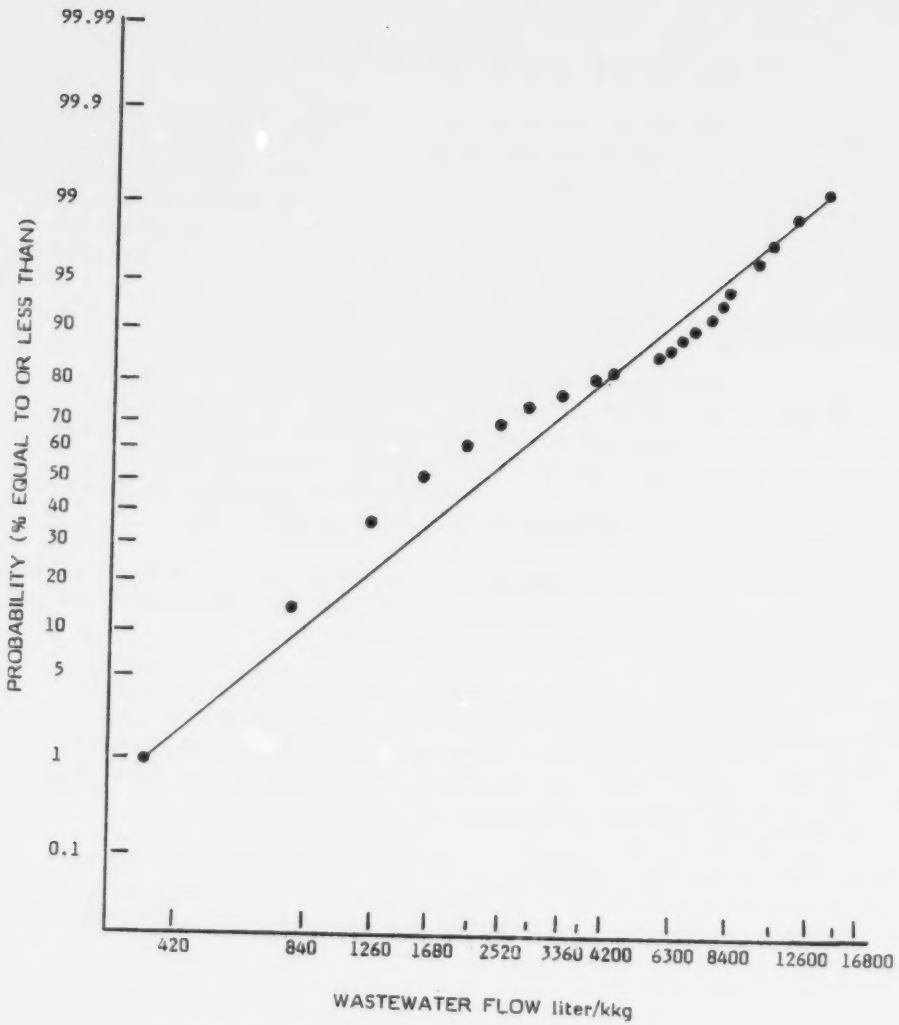

Figure 7. Probability plot: Wastewater volume emission rate for large salmon processing.

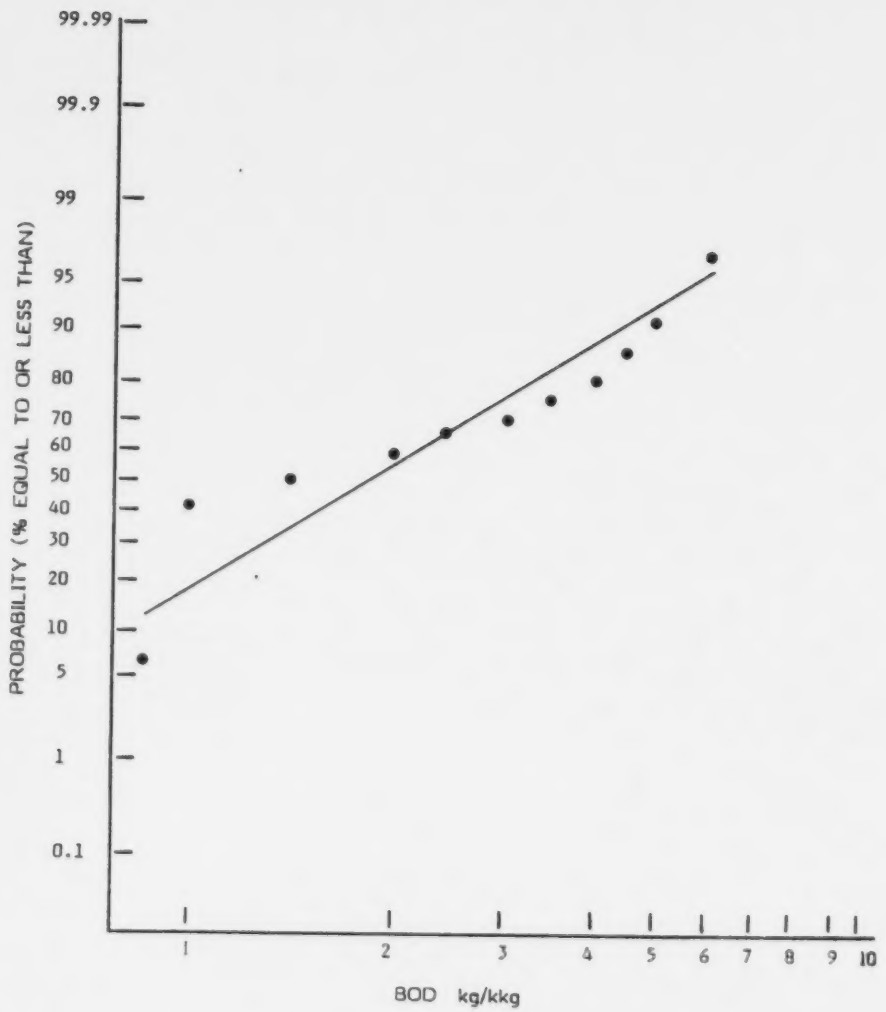

Figure 8. Probability plot: Wastewater biochemical oxygen demand mass emission rate for large salmon processing.

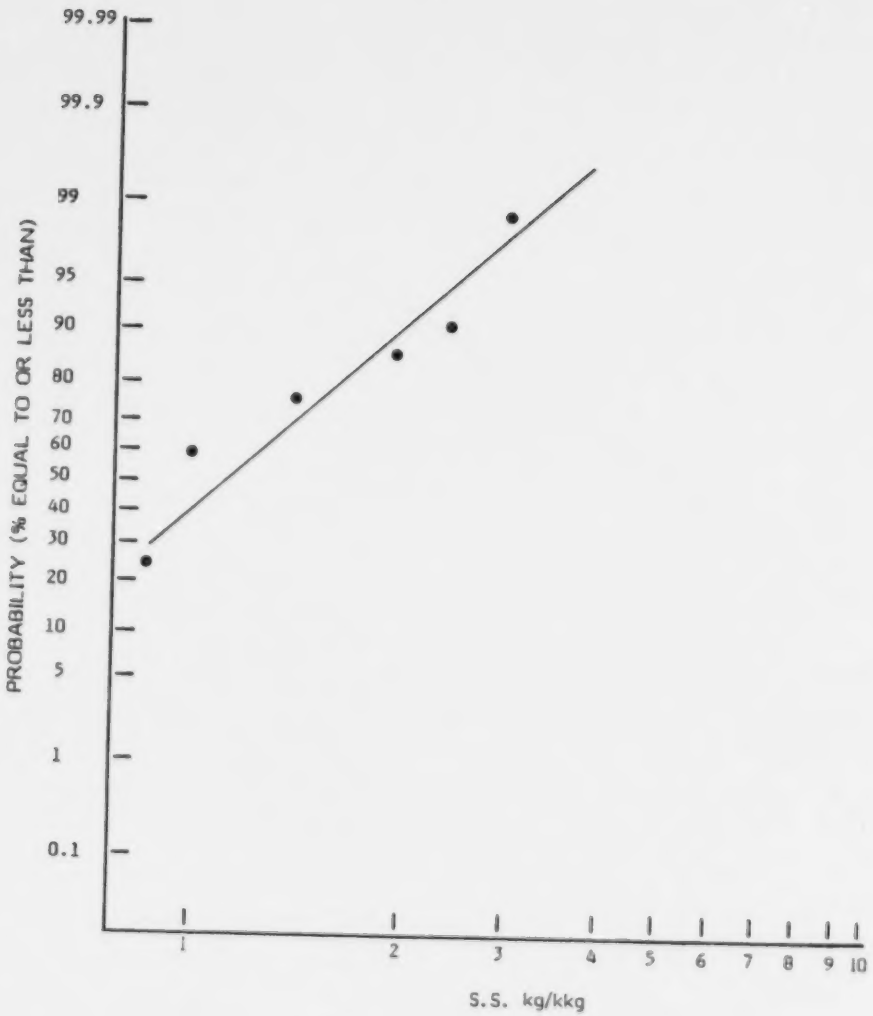

Figure 9. Probability plot: Wastewater suspended solids mass emission rate for large salmon processing.

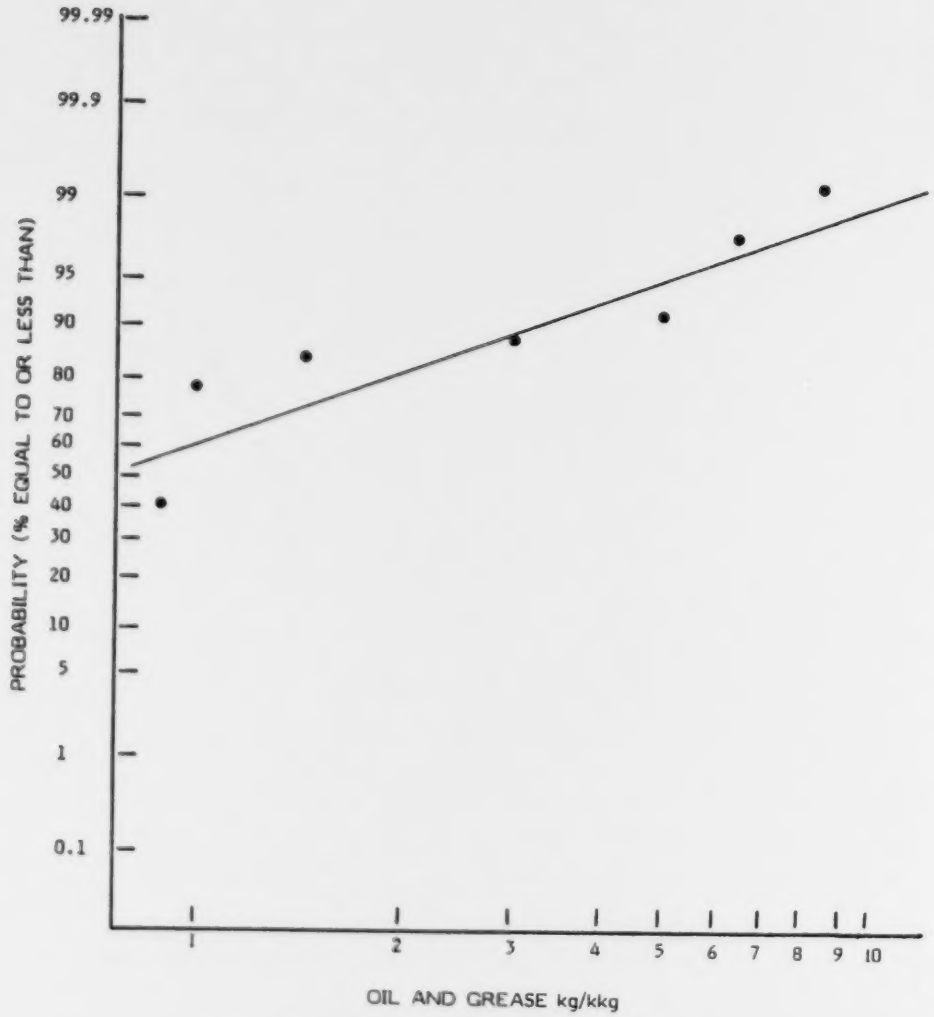

Figure 10. Probability plot: Wastewater oil and grease mass emission rate for large salmon processing.

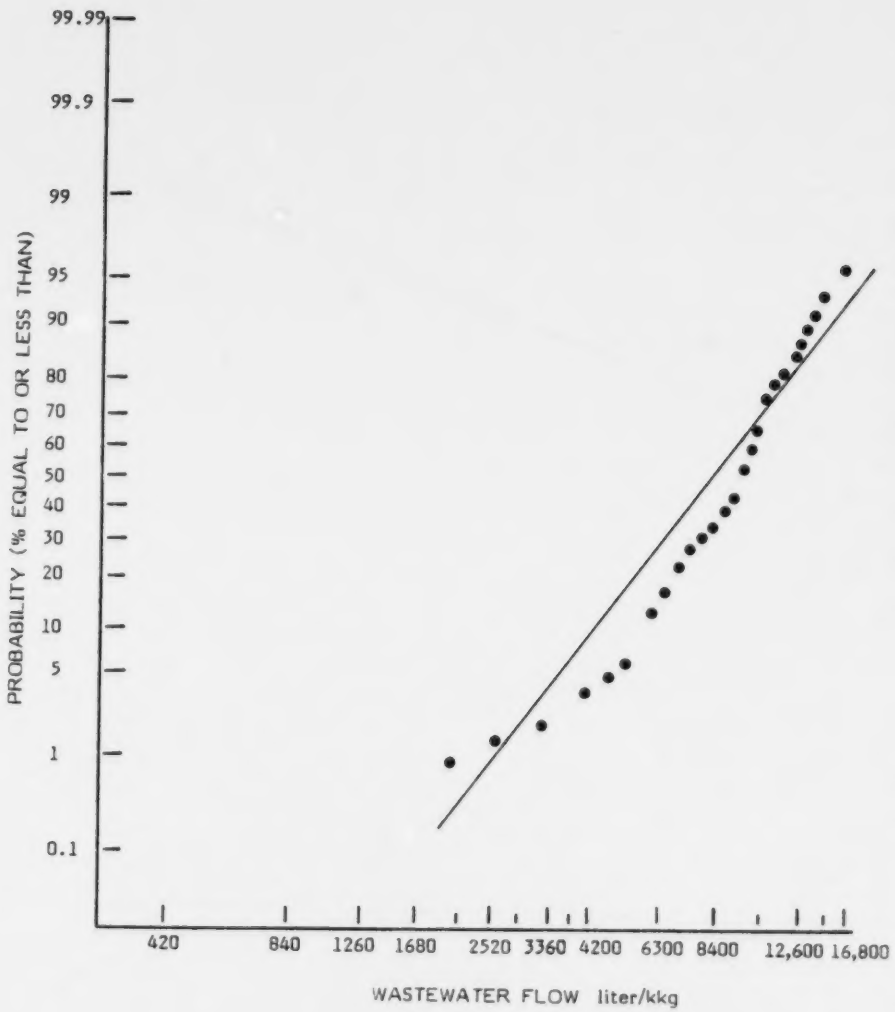

Figure 11. Probability plot: Wastewater volume emission rate for small salmon processing.

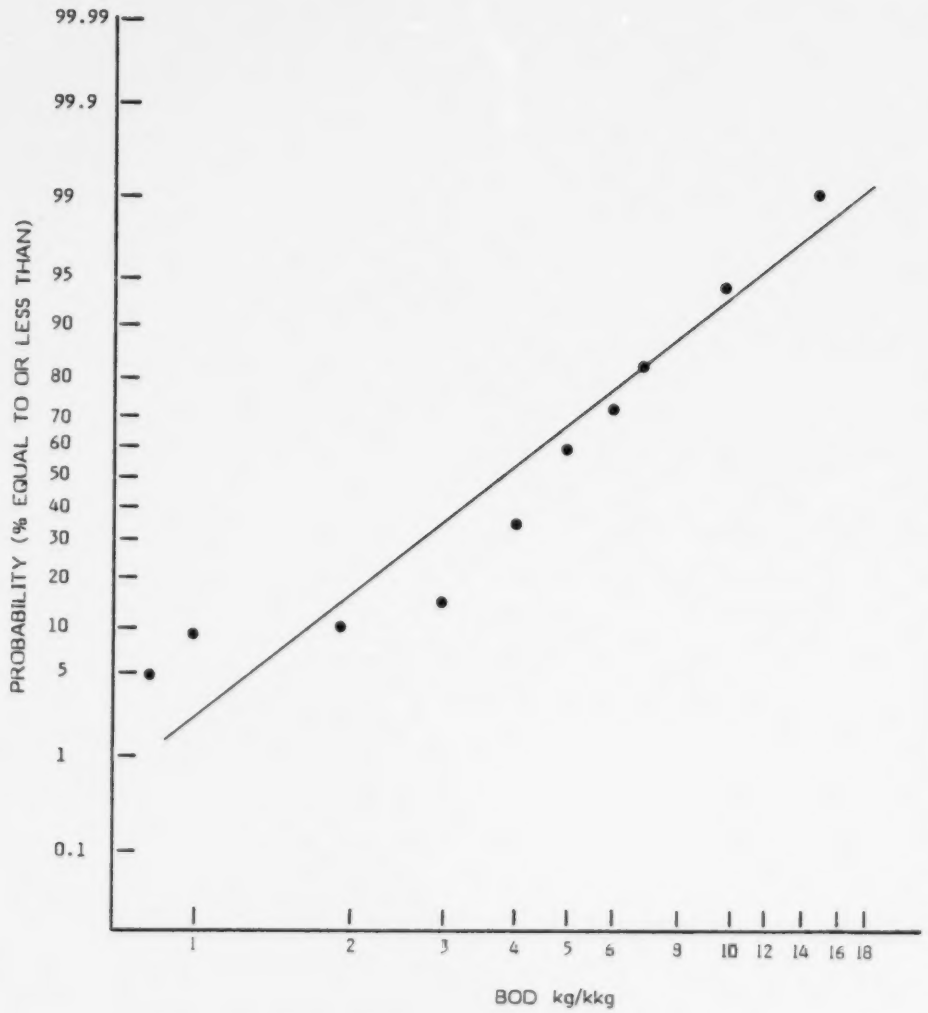

Figure 12. Probability plot: Wastewater biochemical oxygen demand mass emission rate for small salmon processing.

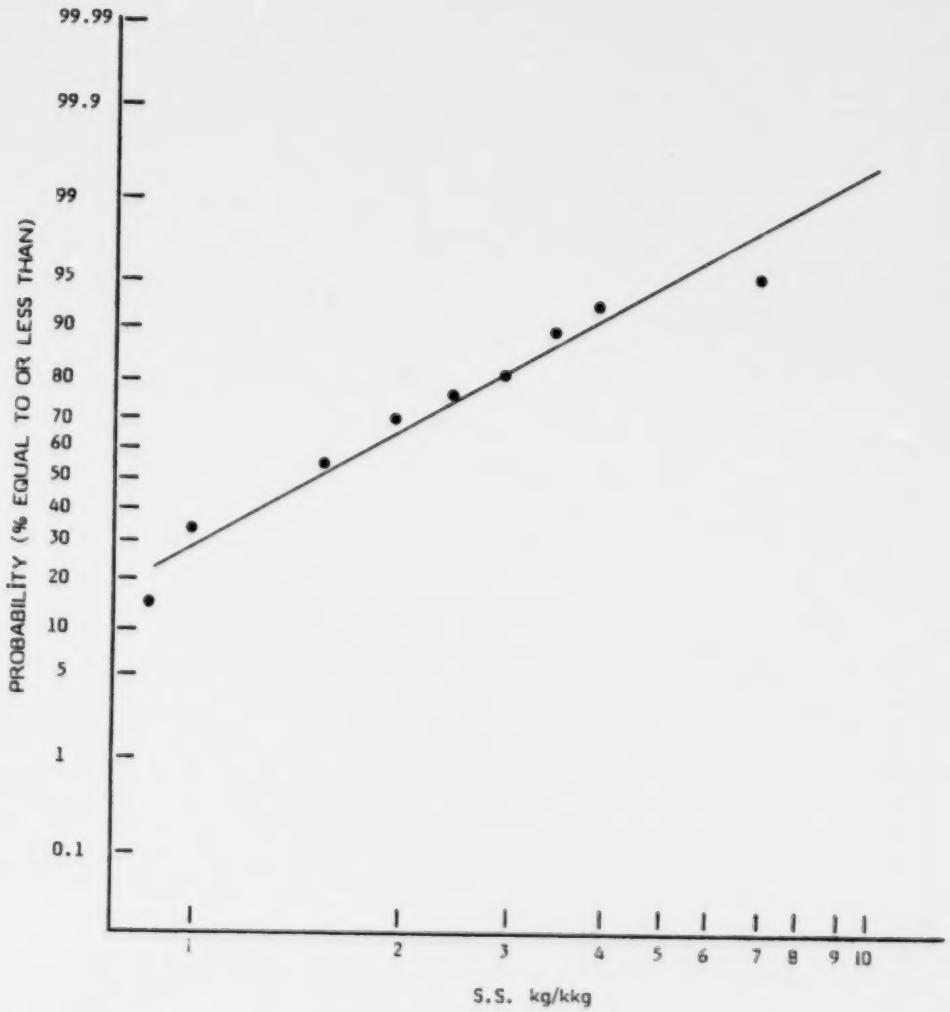

Figure 13: Probability plot: Wastewater suspended solids mass emission rate for small salmon processing.

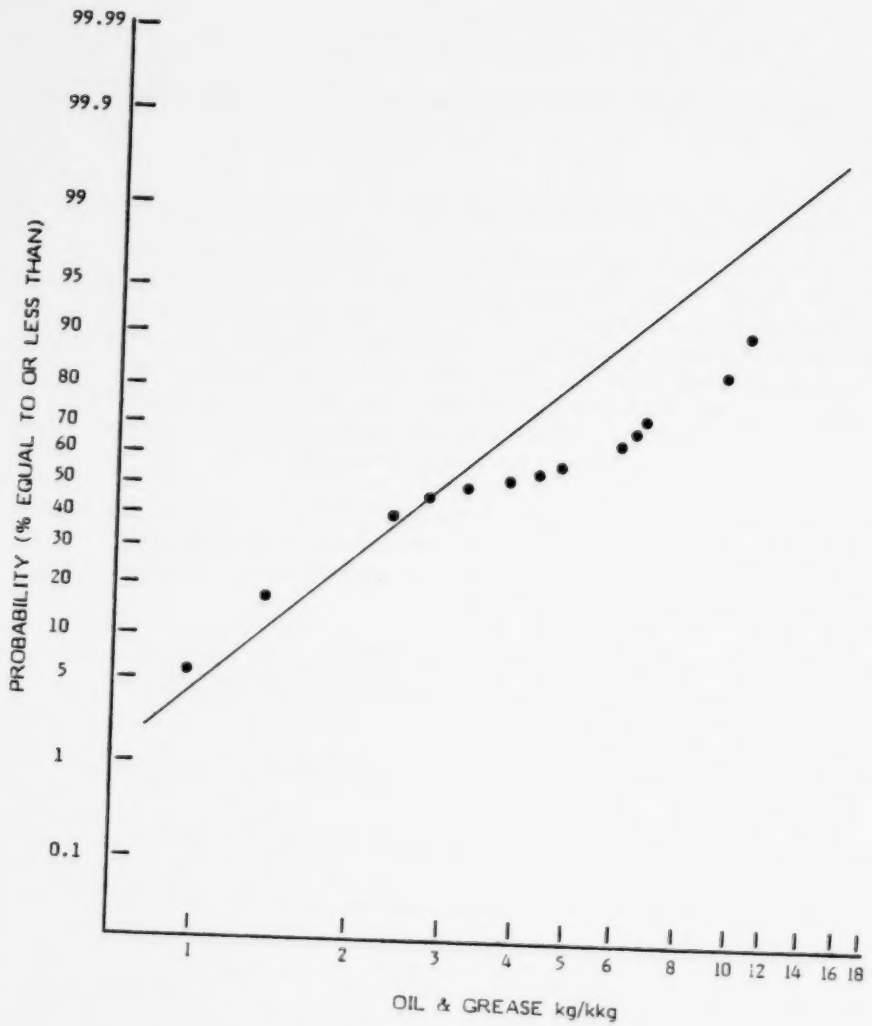

Figure 14. Probability plot: Wastewater oil and grease mass emission rate for small salmon processing.

TABLE 12
MAJOR WASTEWATER CHARACTERISTICS

Parameters	Large Salmon Processing		Small Salmon Processing	
	Average*	95% Probability	Average*	95% Probability
Flow (liter/kkg)	3,122	8,708	9,890	14,630
BOD (kg/kkg)	1.13	5.5	5.2	11.5
SS (kg/kkg)	1.3	2.5	2.2	5.5
Grease and Oil (kg/kkg)	0.8	5.2	2.2	8.2

*Obtained from Table 8.

EFFECT OF F/M RATIO ON TREATMENT EFFICIENCIES

The summary of operating conditions and the treatment efficiencies during the full-scale and pilot plant study were presented in Table 9 and Table 10. To develop the design criteria, an attempt was made to correlate the various operating conditions, such as F/M ratio, DO, etc., to the treatment efficiencies of various parameters. Only the results obtained from the pilot plant were used for the development of design criteria since the desirable operating condition were not achieved during full-scale operation. The effects of operating conditions on the treatment efficiencies during full-scale plant operation are shown in Appendix B.

The following will discuss in detail the effect of F/M ratio on treatment efficiencies. The statistical analysis herein is to utilize the equation derived from polynomial regression to demonstrate the relationship between two variables. For the discussion here, a polynomial regression of degree of 3 was chosen.

The relationship between BOD removal efficiency and F/M ratio during pilot plant study is detailed in Figure C-1 of Appendix C and is presented in Equation 1:

$$BOD_5 \text{ rem.} = 44.98 + 399\,(F/M) - 1099\,(F/M)^2 + 813\,(F/M)^3 \qquad \text{Equation 1}$$

By solving the equation, an F/M ratio of 0.25 is indicated to produce a BOD_5 removal efficiency of about 89% during pilot plant operation. This ratio of 0.25 would yield almost maximum SS removal efficiency of 77% as presented in Equation 2 (Figure C-2 of Appendix C)

$$SS \text{ rem.} = 46 + 314\,(F/M) - 940\,(F/M)^2 + 735\,(F/M)^3 \qquad \text{Equation 2}$$

During the pilot plant study, the effects of F/M ratio on the removal efficiencies of SS, COD, grease and oil, TKN, ammonia, ortho-phosphate and total-phosphate are presented in Appendix C. Applying the derived equations shown in respective figures, an F/M ratio of 0.25 would produce the following removal efficiencies in the pilot plant:

Parameter	Removal Efficiency (%)
BOD_5	89
SS	77
COD	83
Grease and Oil	75
TKN	77
Ammonia	60
Ortho-phosphate	51
Total-phosphate	41

It should be noted that during the pilot plant study the F/M ratio of 0.25 would yield excellent removal efficiencies for BOD_5, SS, COD, grease and oil, TKN, ammonia, ortho-phosphate and total-phosphate. Therefore, it is recommended that an F/M ratio of 0.25 be considered for design of treatment systems for salmon processing wastewaters.

EFFECT OF DETENTION TIME ON TREATMENT EFFICIENCIES

Hydraulic detention time is an important factor to be considered for design of a wastewater treatment system. The statistical analysis used for the discussion is similar to that used for the F/M ratio.

The relationship between detention time and BOD removal efficiency during the pilot plant study is detailed in Figure C-9 of Appendix C and is presented in the following equation:

$$BOD_5 \text{ rem.} = 26.4 + 61.9\,(DT) - 15.4\,(DT)^2 + 1.0\,(DT)^3 \qquad \text{Equation 3}$$

To develop the design criteria for detention time, a BOD removal efficiency of 89% was selected which was found to be the efficiency achieved when the F/M ratio is 0.25 (see Equation 1). The above equation indicates that a detention time of 1.5 days (36 hours) is needed for 89% BOD removal efficiency. By using the derived equations presented in Figures C-10 through C-16 of Appendix C, a detention time of 1.5 days would generate the following removal efficiencies for the pilot plant operation:

Parameter	Removal Efficiency (%)
BOD_5	89
SS	74
COD	86
Grease and Oil	69
TKN	75
Ammonia	60
Ortho-phosphate	44
Total-phosphate	43

It is interesting to note that the removal efficiencies obtained from an F/M ratio of 0.25 are quite similar to those generated from a detention time of 1.5 days. Based on the above discussion, it is recommended that a detention time of 1.5 days be considered for design of biological treatment systems for salmon processing wastewaters.

EFFECT OF DISSOLVED OXYGEN ON TREATMENT EFFICIENCIES

Similar to the F/M ratio and detention time exercises, the polynomial regression method was used here to present the relationship between dissolved oxygen (DO) content and treatment efficiencies during both full-scale and pilot plant study. The relationships are detailed in Appendix B and Appendix C. The exercise was inconclusive.

During the pilot plant study, the average DO content was 2.4 mg/l with a standard deviation of 1.5 mg/l. Considering practical operating limitations, it is felt that a DO content of 2 ppm would assure both adequate dissolved oxygen and sufficient mixing in the aeration chamber. Therefore, it is recommended that a DO content of 2 ppm be used for design of treatment systems for salmon processing wastewaters.

EFFECT OF OVERFLOW RATE ON TREATMENT EFFICIENCIES

In addition to the above discussions related to aeration chamber, it is essential to consider overflow rate in the clarifier. Treatment efficiencies are controlled by the operating conditions in both the aeration chamber and the clarifier.

For the development of overflow rate criteria, the pilot plant study results were used. The effect of overflow rate on the removal efficiencies of BOD, SS, COD, grease and oil, TKN, ammonia, ortho-phosphate and total-phosphate during the pilot plant study are shown in Figures C-25, C-26, C-27, C-28, C-29, C-30, C-31, C-32 of Appendix C, respectively. The relationship between overflow rate and BOD removal efficiency is described in Equation 4:

$$BOD_5 \text{ rem.} = 111.5 - 0.2\,(OR) + 2 \times 10^{-4}\,(OR)^2 - 1.6 \times 10^{-7}\,(OR)^3$$

Equation 4

To be consistent with the findings of the previous analyses, a 1.5 day detention time (corresponding to 89% BOD removal) was selected for the development of overflow rate in the clarifier. According to the above equation, an overflow rate of 0.062 liter/sec/m^2 is needed for 89% BOD removal. Similarly, the removal efficiencies of other parameter can be computed and are summarized as follows:

Parameter	Removal Efficiency %
BOD	89
SS	82
COD	92
Grease and Oil	81
TKN	80
Ammonia	68
Ortho-phosphate	60
Total-phosphate	33

The removal efficiencies shown above are similar to those obtained from the consideration of F/M ratio, detention time and DO in the aeration chamber. Minor differences are believed to be insignificant in the engineering application. Thus, it is recommended that an overflow rate of 0.062 liter/sec/m^2 be considered for clarifier design.

EFFLUENT CHARACTERISTICS

Effluent characteristics for both the full-scale plant and pilot plant were discussed in Section VI and are summarized in Table 11. To further demonstrate the effluent characteristics, BOD, SS, and grease and oil are plotted on probability paper. The probability herein refers to the percentage measurement equal to or less than the stated class mean of the measured parameter. As mentioned before, only the pilot plant effluent will be discussed here.

Figure 15 indicates that 95% of the time the effluent BOD was about 0.86 kg/kkg or less during pilot plant study. Figure 16 shows that 95% of the time the effluent SS was about 0.6 kg/kkg or less during pilot plant study. Figure 17 reveals that 95% of the time the effluent grease and oil was 0.58 kg/kkg or less during pilot plant study. The effluent characteristics in terms of BOD, SS, and grease and oil during pilot plant study are summarized as follows:

Parameters	Average*	95% Probability
BOD (kg/kkg)	0.65	0.86
SS (kg/kkg)	0.32	0.60
Grease and Oil (kg/kkg)	0.25	0.58

*Obtained from Table 11

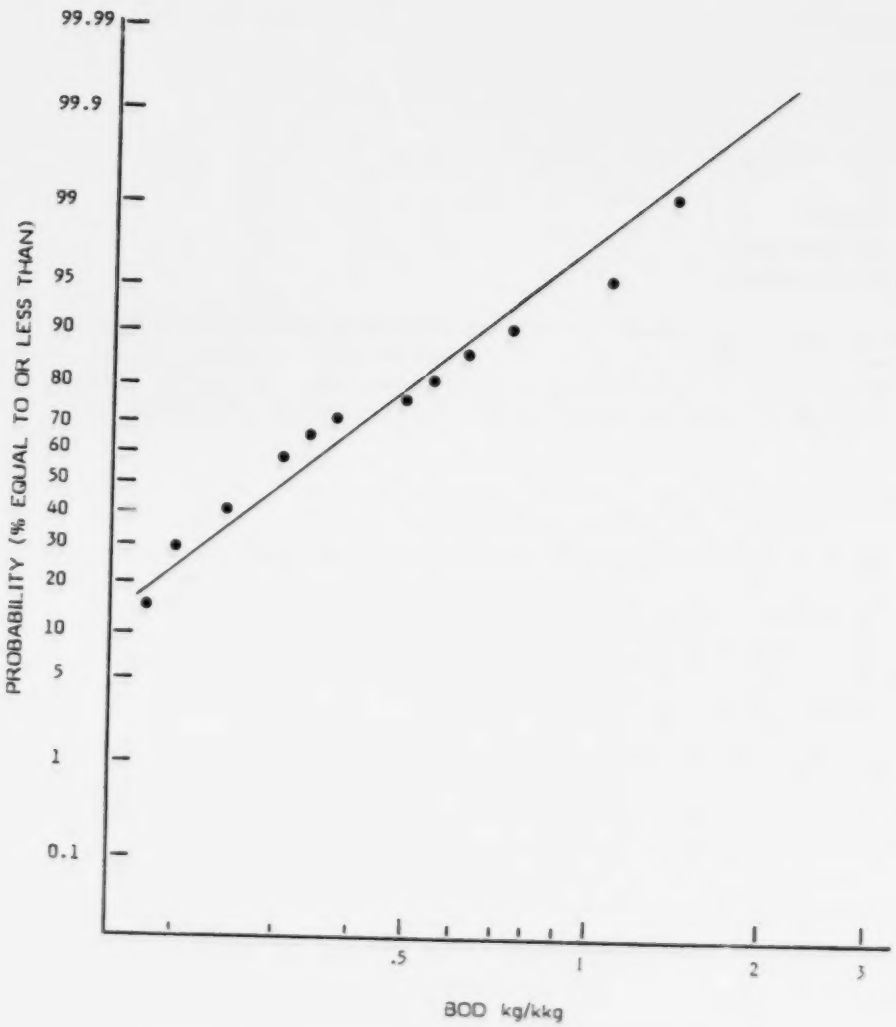

Figure 15. Probability plot: Pilot plant effluent biochemical oxygen demand mass emission rate for large salmon processing.

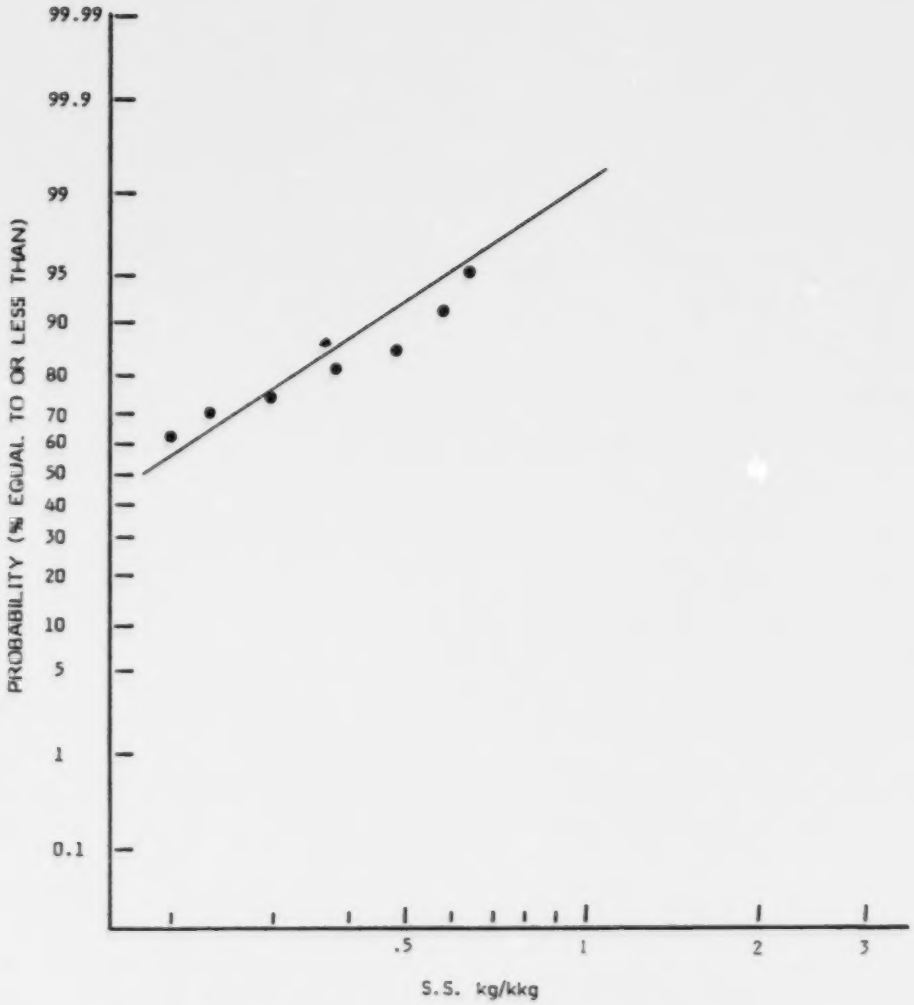

Figure 16. Probability plot: Pilot plant effluent suspended solids mass emission rate for large salmon processing

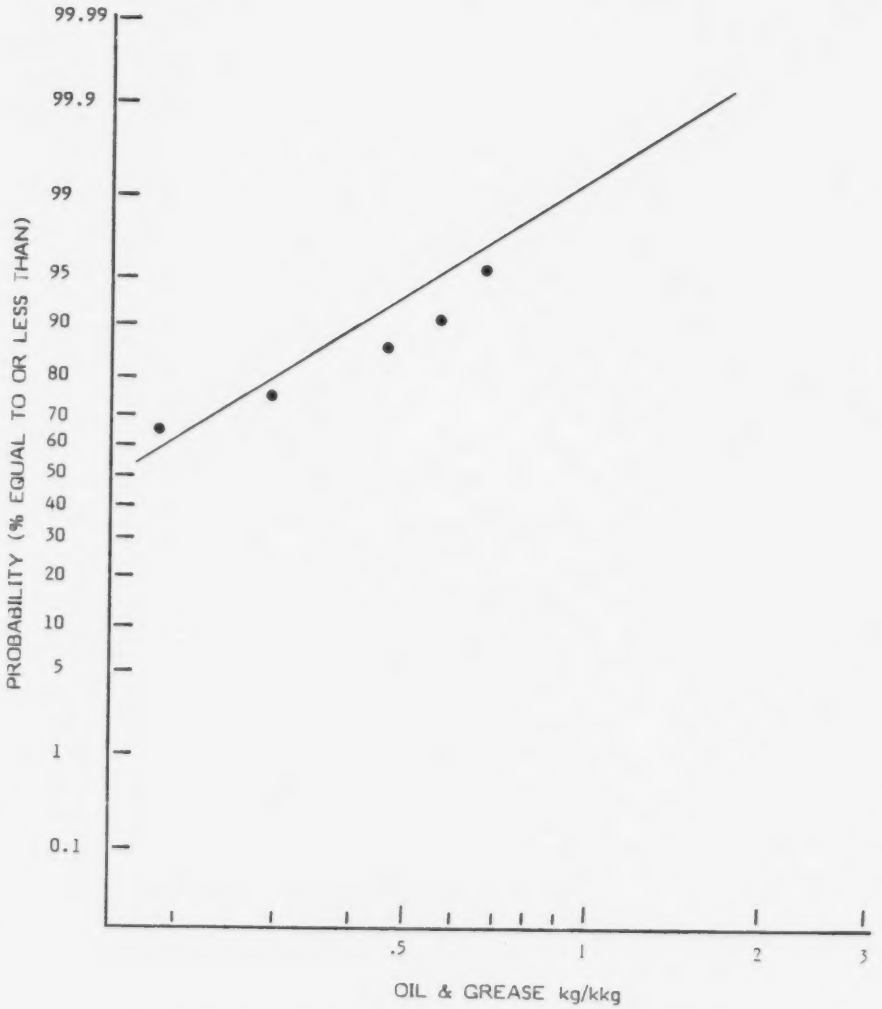

Figure 17. Probability plot: Pilot plant effluent oil and grease mass emission rate for large salmon processing.

OXYGEN UPTAKE RATE

The oxygen uptake rate is an indicator for biological activity of mixed liquor suspended solids in the aeration chamber. The oxygen uptake tests were conducted in the field using YSI DO probe. During sampling days, about 1 liter of MLSS was collected for DO measurement in the field. The sample DO were measured at 0, 60 minutes. The oxygen uptake rate was computed by dividing the decrease in oxygen by the elapsed time. The rate is expressed in terms of mg/l/hr.

An attempt was made to correlate oxygen uptake rate with F/M ratio. Figure 18 illustrates the general effect of F/M ratio on oxygen uptake rate. From the data points shown in Figure 18, a strong correlation between two variables is not readily apparent. It can be generally concluded that the oxygen uptake rate somewhat increases with the increase in F/M ratio.

SLUDGE FILTERABILITY CHARACTERISTICS

Sludge disposal is an important factor in the operation of wastewater treatment systems. During the entire study, all sludge in the clarifier was recycled to the aeration tank. To facilitate analytical work, a sludge filterability test was conducted to indicate sludge dewatering characteristics. The apparatus for filterability test includes vacuum pump, millipore membrane filter funnel and vacuum flash. One hundred milliliters (100 ml) of sludge was filtered under a pressure of 1470 g/cm^2 for 80 minutes, and suspended solid concentrations were measured at 0, 20, 40, 60 and 80 minutes. To demonstrate the sludge filterability, an attempt was made to compare the percent of suspended solids concentration increase to that obtained from conventional activated sludge process while treating domestic wastewater (1). The computations for the percent of suspended solids increase are detailed in Appendix A. The following comparison demonstrated that sludge filterability for the Skokomish Study was about 20% less than that for conventional activated sludge.(1)

	Filtering		Average
	Pressure (g/cm^2)	Time (Min)	Percentage of SS Increase
Skokomish Sludge	1470	20	391
Activated Sludge	350	20	115

SUMMARY OF DESIGN CRITERIA

Based on the above discussion, the design criteria for an extended aeration system treating salmon processing waste can be summarized in Table 13.

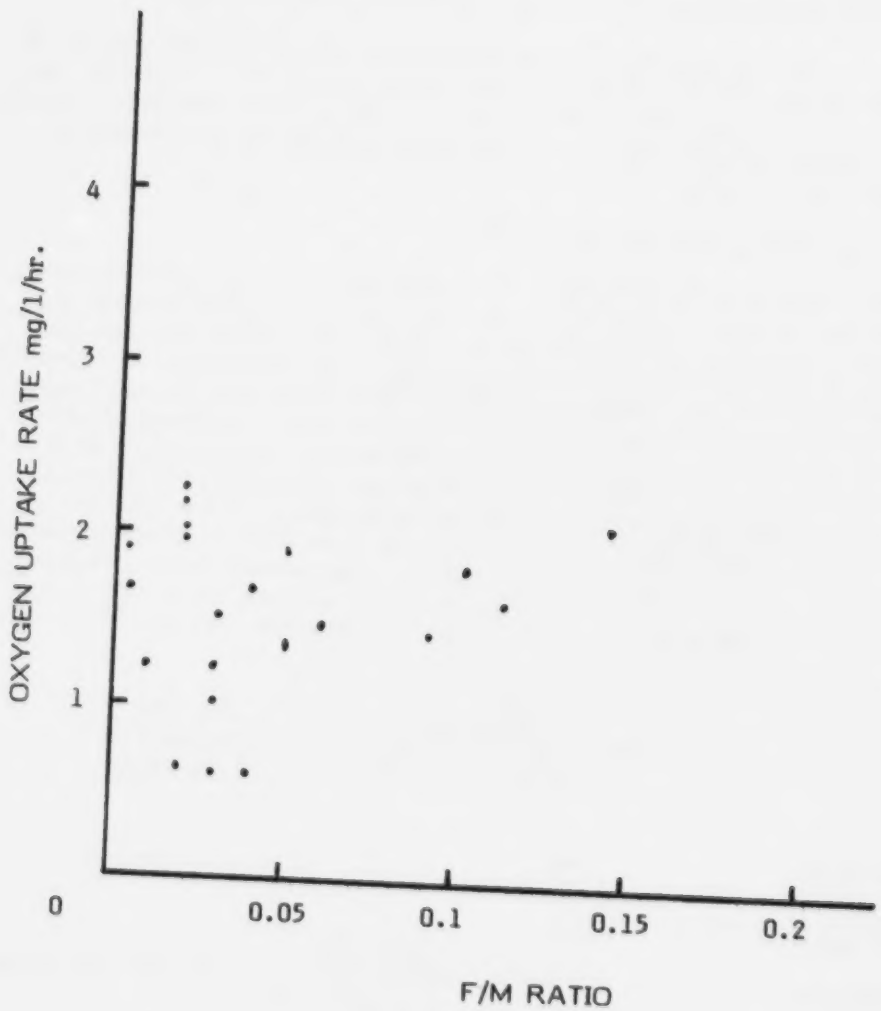

Figure 18. Effect of F/M ratio on oxygen uptake rate.

TABLE 13
SUMMARY OF DESIGN CRITERIA FOR AN EXTENDED AERATION PROCESS TREATING SALMON PROCESSING WASTE

Parameters	Design Criteria
Flow, liter/kkg:	
Large Salmon processing	8,708
Small Salmon processing	14,630
BOD, kg/kkg:	
Large Salmon processing	5.5
Small Salmon processing	11.5
SS, kg/kkg:	
Large Salmon processing	2.5
Small Salmon processing	5.5
Grease and Oil, kg/kkg:	
Large Salmon processing	5.2
Small Salmon processing	8.2
F/M ratio, day^{-1}:	0.25
Detention Time, day:	1.5
DO, ppm:	2.0
Clarifier overflow rate $liter/sec/m^2$:	0.062

SECTION 8

COST EVALUATION

Cost is an important factor for the evaluation of a treatment system. The costs herein refer to construction cost and operation and maintenance cost.

CONSTRUCTION COST

The treatment system as shown in Figure 3 was constructed in 1974 to 1975. The construction was divided into Schedule A and Schedule B. The bid prices in August 1974, for both schedules are summarized as follows:

	Items	Bidding Price
Schedule A	Pump Station, piping, outfall and two aerobic ponds and Diversion Box	$33,215
Schedule B	Extended Aeration package plant	$38,945
	Total	$72,160

The extended aeration system alone (without two aerobic ponds) was found capable of meeting the recommended guidelines. The construction cost for the extended aeration treatment system (including package plant, pump station, piping and outfall) was $62,510, based on ENR 1894. The construction cost is escalated to be $104,326 based on ENR 3161 for July 1978.

OPERATION AND MAINTENANCE COST

A comprehensive maintenance program is essential to consistently maintain an adequate degree of treatment. Basically the maintenance required falls into one of two categories: (1) preventive maintenance; and (2) corrective maintenance. Preventive maintenance should be performed on a regular basis to maintain the equipment and ensure satisfactory operation. Corrective maintenance will be required when equipment has failed and is in need of repair.

The manpower required to maintain and operate the extended aeration treatment system was found to be approximately 1 man-hour for each working day. In other words, 260 man-hours were needed per year. Power requirements for the system were found to be an average of 25 KWH/day with a range of 8 to 122 KWH/day. The computation of O&M costs are summarized below.

Labor: 260/365 x 1 x $8/m-hour = $5.70/day

Power Cost: 25 KWH/day x $0.03/KWH = $0.75/day

Total O&M cost = $6.45/day

TOTAL COST

To facilitate the cost evaluation, it is essential to amortize the construction cost along with the O&M cost to develop the total cost per kkg of salmon processed. For this study, the amortization period was selected at 20 years with a 7% interest rate. The total cost (ENR 3161) for the extended aeration treatment system was computed as follows:

Total cost = (104,326 x 0.09439 x 1/365) + $6.45/day = $33.43 /day

The computation of total cost per kkg of salmon processed was based on using the design criteria developed from this study. According to recommended design criteria of 1.5 days detention time, the full-scale extended aeration system is capable of treating 50,540 liter/day of wastewater. The computations of total cost per kkg of salmon processed are summarized as follows:

	Large Salmon	Small Salmon
Liter/day of wastewater which can be treated	50,540	50,540
kkg of salmon processed per day	5.8(1)	3.5(2)
Total cost per day	$33.43	$33.43
Total cost per kkg of salmon processed	$ 5.76	$ 9.55

Note: (1) Using recommended Design Criteria for large salmon 8,708 liter/kkg

(2) Using recommended Design Criteria for small salmon 14,630 liter/kkg

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APPENDIX A

RESULTS OF SLUDGE FILTERABILITY TESTS

One hundred milliliters (100ml) of the sludge was filtered under a pressure of 21 psi (1470 g/cm^2) for 80 minutes, and suspended solids concentrations were measured at 0, 20, 40, 60, and 80 minutes. The numbers in brackets are the percentage increase in suspended solids from previous measurements of solid content. The results are summarized on Table A-1.

An attempt was made to compare percents of SS increase for this study to those obtained from 0.063 liter/sec pilot plant with activated sludge process. Table A-2 shows the percent of SS increase for the activated sludge plant.

For a reasonable comparison, the percent of SS increase from 60 minutes to 80 minutes for extended aeration treatment system should be used. Solids concentrations for the two sampling times for both studies were very similar.

TABLE A-1

EXTENDED AERATION TREATMENT SYSTEM

RESULTS OF SLUDGE FILTERABILITY

SS mg/l

Date	0 min	20 min	40 min	60 min	80 min	100 min
11/18/75	950	1,188(125)	1,727(145)	2,568(149)	5,277(205)	31,667(600)
11/21/75	1,050	1,364(130)	1,909(140)	3,387(177)	7,000(207)	35,000(500)
11/26/75	1,100	1,467(133)	2,075(141)	3,438(166)	6,875(200)	36,667(533)
12/02/75	850	1,581(186)	2,229(141)	3,432(154)	7,069	60,920(850)
12/05/75	1,950	2,321(119)	2,959(127)	3,980(135)	5,909(148)	10,263(174)
12/12/75	2,050	2,628(128)	3,596(137)	6,212(173)	12,058(194)	102,500(850)
1/16/76	1,200	1,622(135)	2,500(154)	4,800(192)	30,000(625)	-
1/23/76	1,300	1,625(125)	2,407(148)	3,714(154)	13,000(350)	-
1/30/76	1,400	1,772(127)	2,592(146)	5,000(192)	96,666(1933)	-
2/05/76	850	1,062(125)	1,545(145)	3,400(220)	28,333(833)	-
3/5/76	2,300	2,839(123)	3,538(125)	4,340(123)	6,252(144)	9,583(153)
3/15/76	2,300	2,949(128)	3,593(122)	4,600(128)	6,571(143)	19,166(292)
4/28/76	2,400	2,963(123)	3,809(128)	5,853(154)	8,511(146)	15,000(175)
5/4/76	2,900	4,754(163)	6,042(127)	10,357(171)	24,166(233)	36,250(150)
5/6/76	3,000	4,167(139)	5,454(131)	7,895(145)	17,647(223)	37,500(212)
5/13/76	3,255	4,173(128)	7,233(173)	7,750(107)	11,625(150)	2,959(255)
5/18/76	3,500	5,303(152)	7,447(140)	14,000(188)	29,166(208)	43,750(150)
5/20/76	3,275	4,366(133)	8,397(192)	20,468(244)	36,389(178)	
6/15/76	5,220	7,791(149)	11,863(152)	74,571(628)		
10/5/76	2,233	4,207(188)	15,928(379)			
10/11/76	2,350	4,273(182)	13,823(323)			
10/15/76	2,467	4,950(200)		49,400( )		
10/22/76	2,100	3,281(156)		70,000( )		
10/25/76	1,750		2,573( )	87,500(3387)		
11/2/76	2,367	3,537(149)	5,267(148)	13,882(264)		
11/5/76	2,250	3,629(161)	4,688(129)	6,818(145)		
9/29/77	2,100	2,917(139)		6,363( )		
10/16/77	2,250	2,960(131)	3,629(123)	5,113(141)		
11/2/77	2,150	2,905(135)	3,359(115)	5,119(152)		
						Avg. (391)

TABLE A-2

ACTIVATED SLUDGE PLANT

RESULTS OF SLUDGE FILTERABILITY

SS mg/l

Date	Initial	Final	Percent of Increase in S.S.
6/17/71	4,460	4,560	102
6/18/71	4,360	5,300	122
6/19/71	3,690	4,100	111
6/21/71	6,380	7,240	113
6/22/71	9,720	10,760	111
6/23/71	3,540	3,780	107
6/24/71	8,100	9,220	114
6/25/71	6,000	7,020	117
6/26/71	5,200	7,540	145
6/27/71	9,680	11,220	112
6/29/71	4,020	4,780	119
		Avg.	115

Notes: 1) Settled activated sludge from a 1 gpm pilot plant was used.

2) Two liters of sludge was filtered under a pressure of about 350 g/cm^2 for 20 minutes.

APPENDIX B

EFFECTS OF OPERATING CONDITIONS ON TREATMENT EFFICIENCIES DURING FULL-SCALE PLANT OPERATION

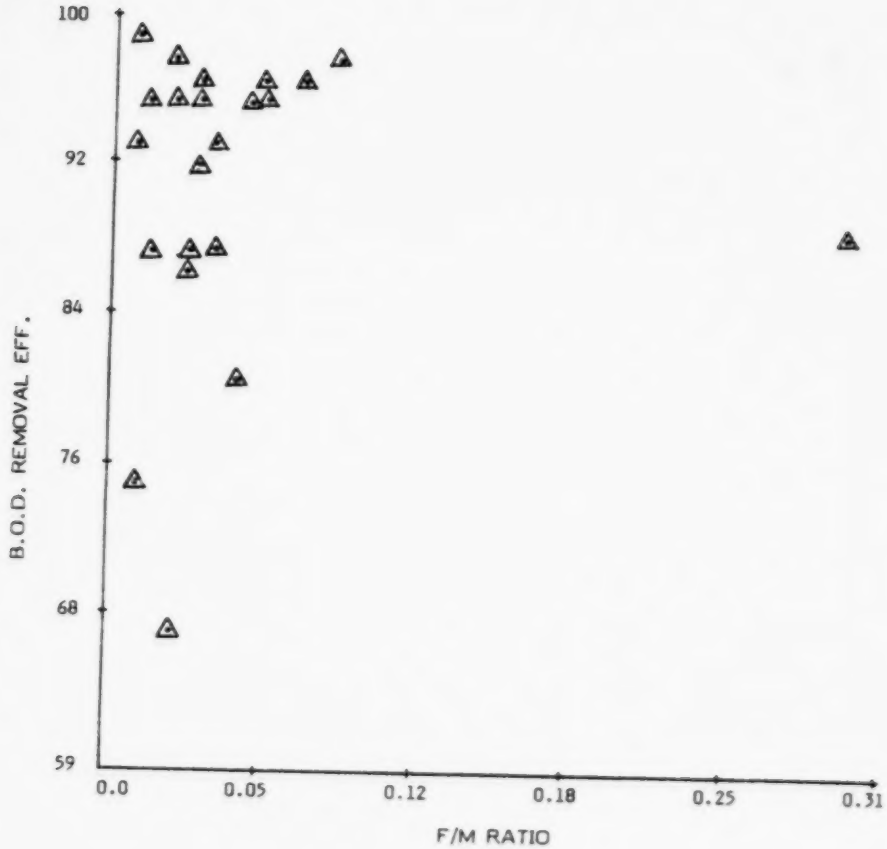
The statistical analysis herein is to utilize the equation derived from polynomial regression to demonstrate the relationship between two variables. Polynomial regression is a statistical technique for finding the coefficients b_o, b_1, b_2 ---- b_m in the functional relationship of the form

$$Y = b_o + b_1X + b_2X^2 + \text{----} + b_mX^m$$

between a dependent variable Y and a single independent variable X. Powers of an independent variable are generated to calculate polynomials of successively increasing degrees. For the discussion here, a polynomial regression of degree of 3 is chosen.

The results during full-scale plant operations are presented in Figures B-1 through Figure B-32. The conversion of gpd/ft^2 is as follows:

$$1 \text{ gpd/ft}^2 = 4.73 \times 10^{-4} \text{ liter/sec/m}^2$$



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
F/M	0.044	0.061	0.013	0.304	0.002	0.302
B.O.D.	89.657	9.881	2.060	98.570	62.025	36.545

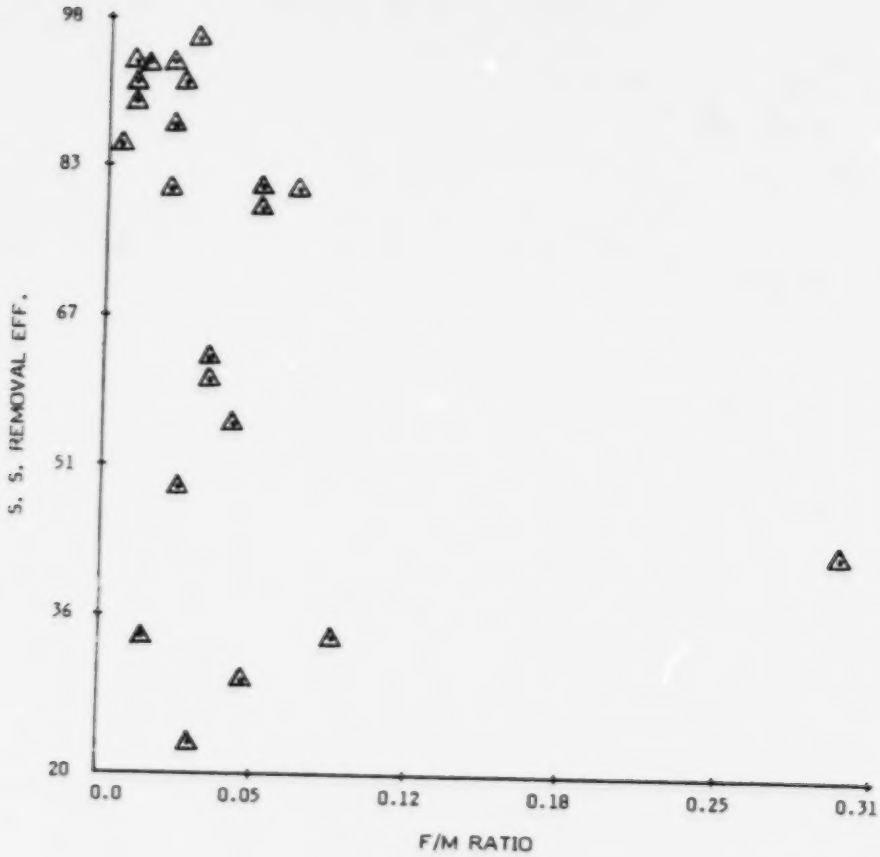
B.O.D. REMOVAL EFF. = $80.72 + 426.5(F/M) - 3503(F/M)^2 + 7217.6(F/M)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-1 EFFECT OF F/M RATIO ON B.O.D. REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
F/M	0.044	0.061	0.013	0.304	0.002	0.302
S. S.	70.470	23.874	4.978	94.444	24.000	70.444

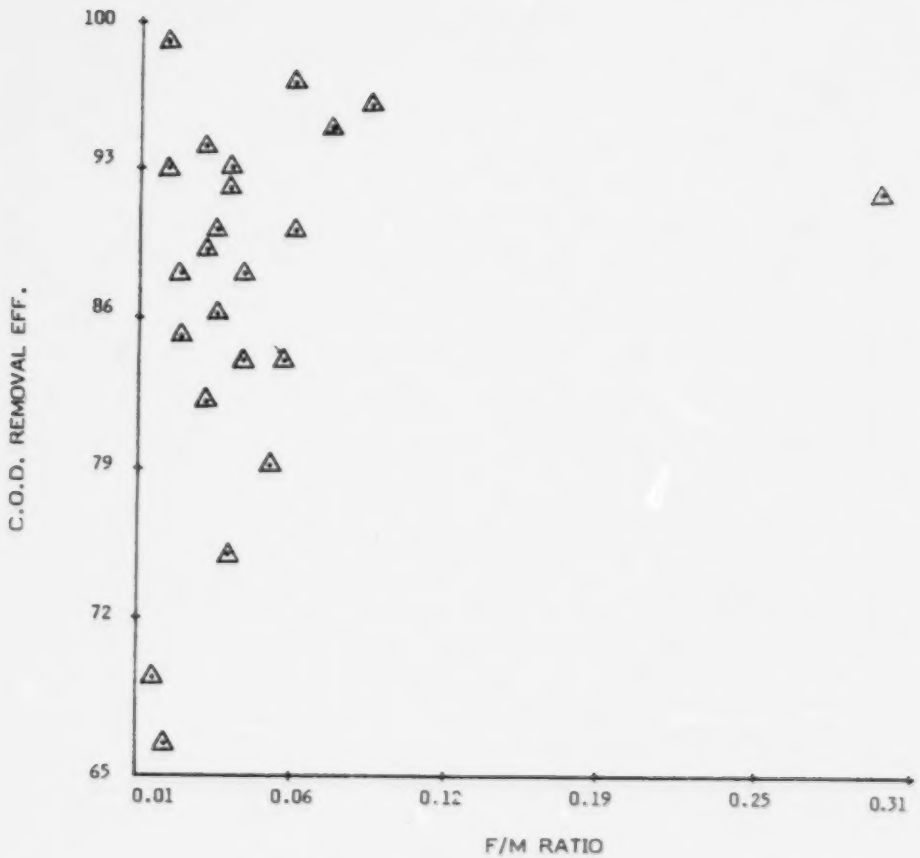
S. S. REMOVAL EFF. = $85 - 509(F/M) + 1768(F/M)^2 - 1832(F/M)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-2 EFFECT OF F/M RATIO ON SUSPENDED SOLIDS REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
F/M	0.044	0.061	0.013	0.304	0.002	0.302
COD	87.123	8.27		96.321	66.792	29.519

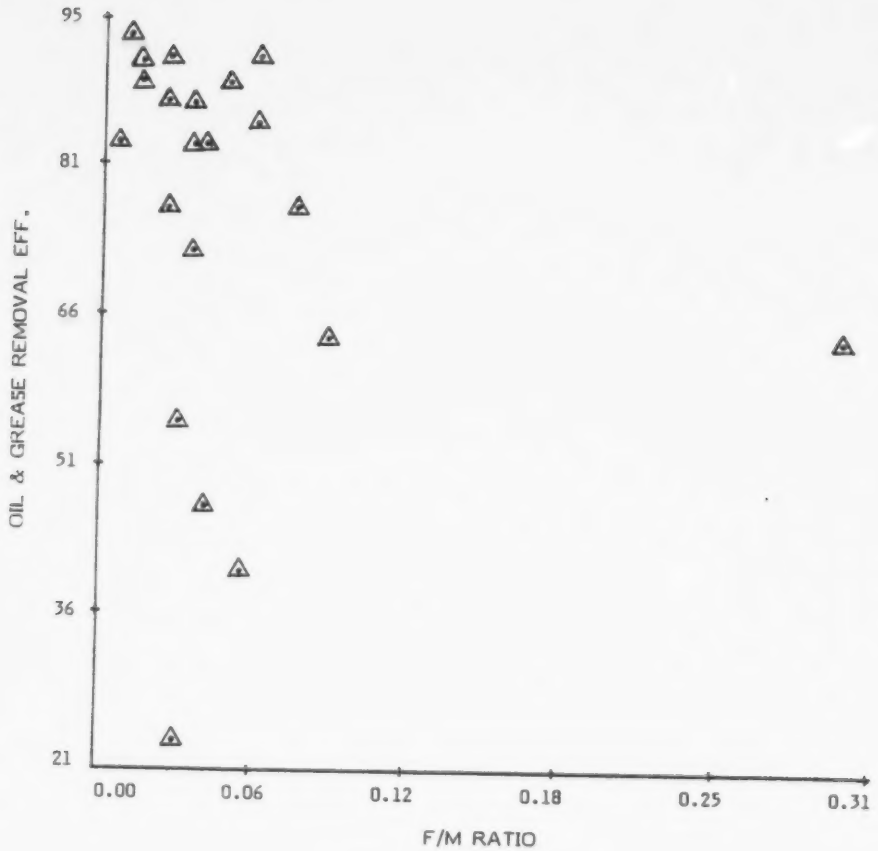
C.O.D. REMOVAL EFF. = 85.2 + 3.9 (F/M) + 1661 $(F/M)^2$ - 5259 $(F/M)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 39 gpd/ft^2

FIGURE B-3 EFFECT OF F/M RATIO ON C.O.D. REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
O & G	74.372	18.539	4.046	91.787	25.000	66.787
F/M	0.047	0.063	0.014	0.304	0.002	0.302

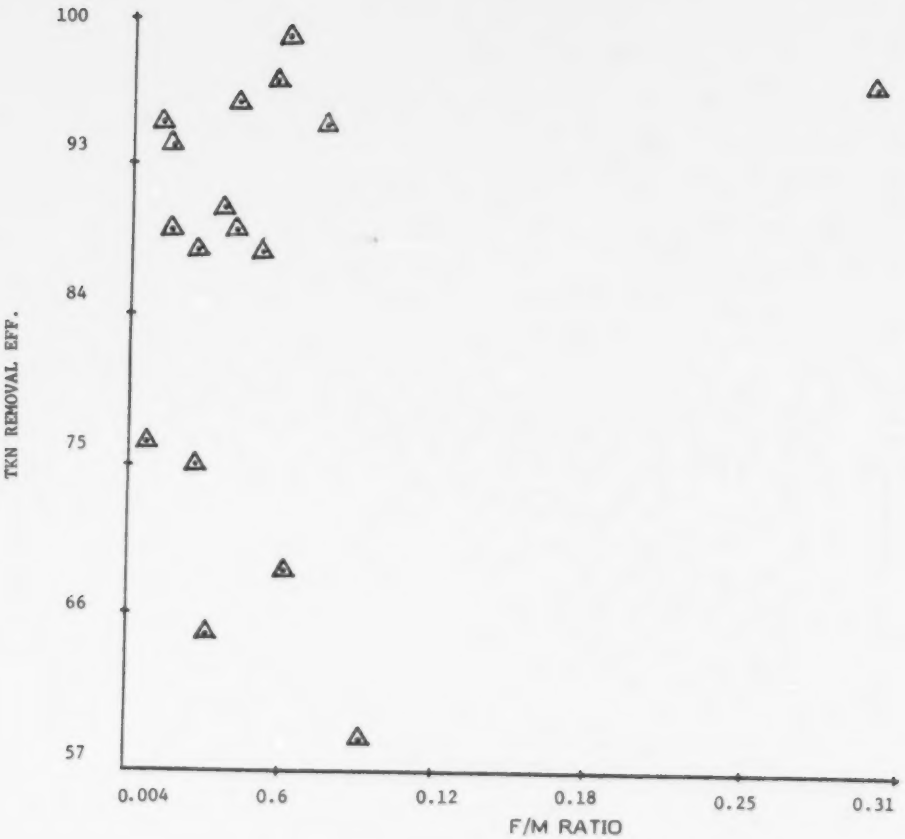
OIL & GREASE REMOVAL EFF. = $88 - 704(F/M) + 7702(F/M)^2 - 18{,}596(F/M)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-4 EFFECT OF F/M RATIO ON OIL & GREASE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TKN	86.221	11.899	2.805	99.620	59.524	40.096
F/M	0.051	0.067	0.016	0.304	0.002	0.302

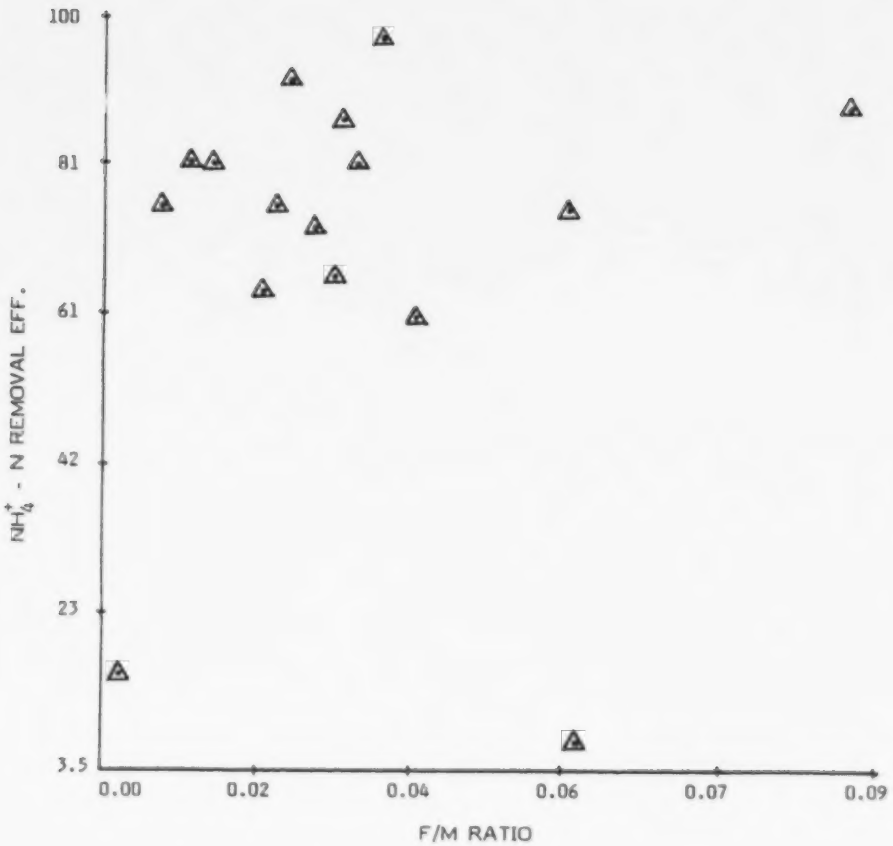
TKN REMOVAL EFF. = $80.5 + 558(F/M) - 9{,}728(F/M)^2 + 26{,}567(F/M)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-5 EFFECT OF F/M RATIO ON TOTAL KJELDAHL NITROGEN REMOVAL EFFICIENCY FOR FULL SCALE PLANT

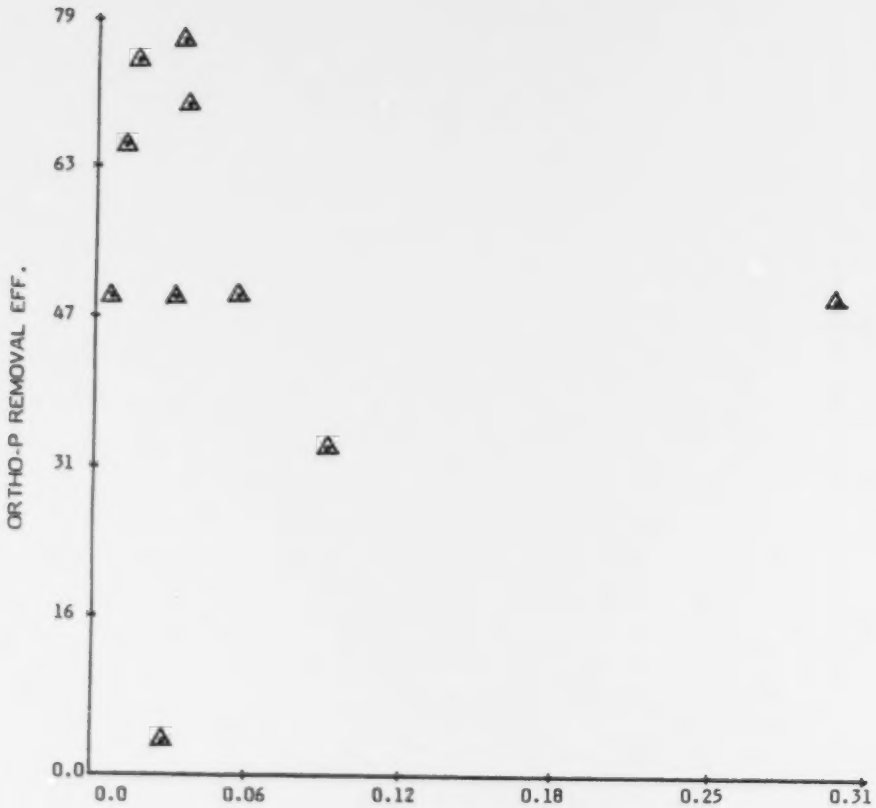


	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
NH_4^+ - N	69.477	25.382	6.554	95.062	8.333	86.728
F/M	0.030	0.023	0.006	0.090	0.002	0.088

NH_4^+ - N REMOVAL EFF. = $27.4 + 5{,}548(F/M) - 161{,}580(F/M)^2 + 1{,}193{,}450(F/M)^3$

OVERFLOW RATE
MEAN = 40 gpd/ft^2
STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-6 EFFECT OF F/M RATIO ON AMMONIA REMOVAL EFFICIENCY FOR FULL SCALE PLANT

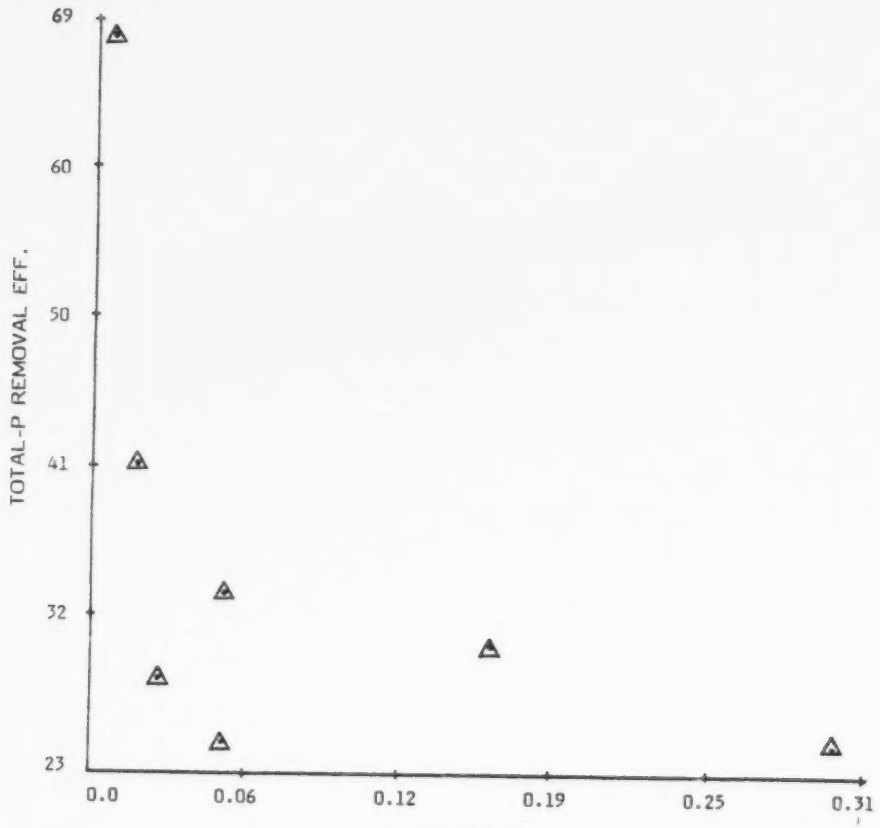


	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
ORTHO-P	51.916	21.392	6.765	75.000	3.750	71.250
F/M	0.057	0.090	0.029	0.304	0.002	0.302

ORTHO-P REMOVAL EFF. = $53.5 + 215(F/M) - 6{,}249(F/M)^2 + 18{,}123(F/M)^3$

OVERFLOW RATE
MEAN = 40 gpd/ft^2
STANDARD DEVIATION = 37 gpd/ft^2

FIGURE 8-7 EFFECT OF F/M RATIO ON ORTHO-PHOSPHATE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TOTAL-P	36.657	15.872	6.480	66.667	25.000	41.667
F/M	0.078	0.112	0.046	0.304	0.009	0.295

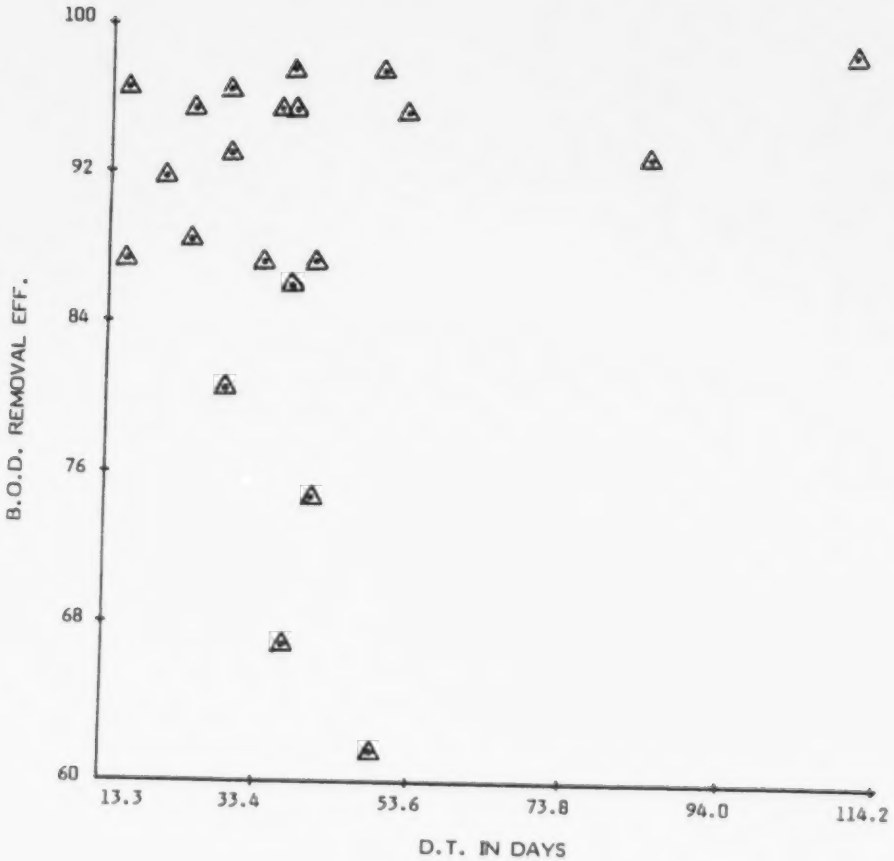
TOTAL-P REMOVAL EFF. = $63 - 819(F/M) + 2286(F/M)^2$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-8 EFFECT OF F/M RATIO ON TOTAL - PHOSPHATE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
D.T.	39.462	21.195	4.420	111.111	16.461	94.650
B.O.D.	89.657	9.881	2.060	98.570	62.025	36.545

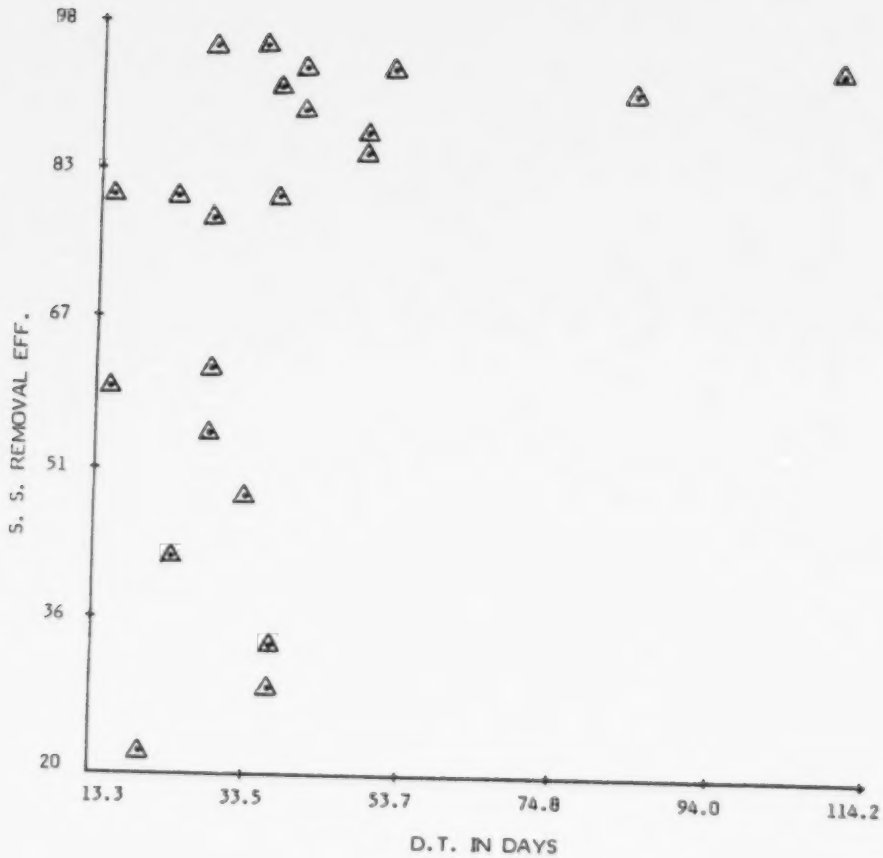
B.O.D. REMOVAL EFF. = $102.7 - 0.582(DT) + 0.005(DT)^2$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-9 EFFECT OF DETENTION TIME ON B.O.D. REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
D.T.	39.462	21.195	4.420	111.111	16.461	94.650
S.S.	70.470	23.874	4.978	94.444	24.000	70.444

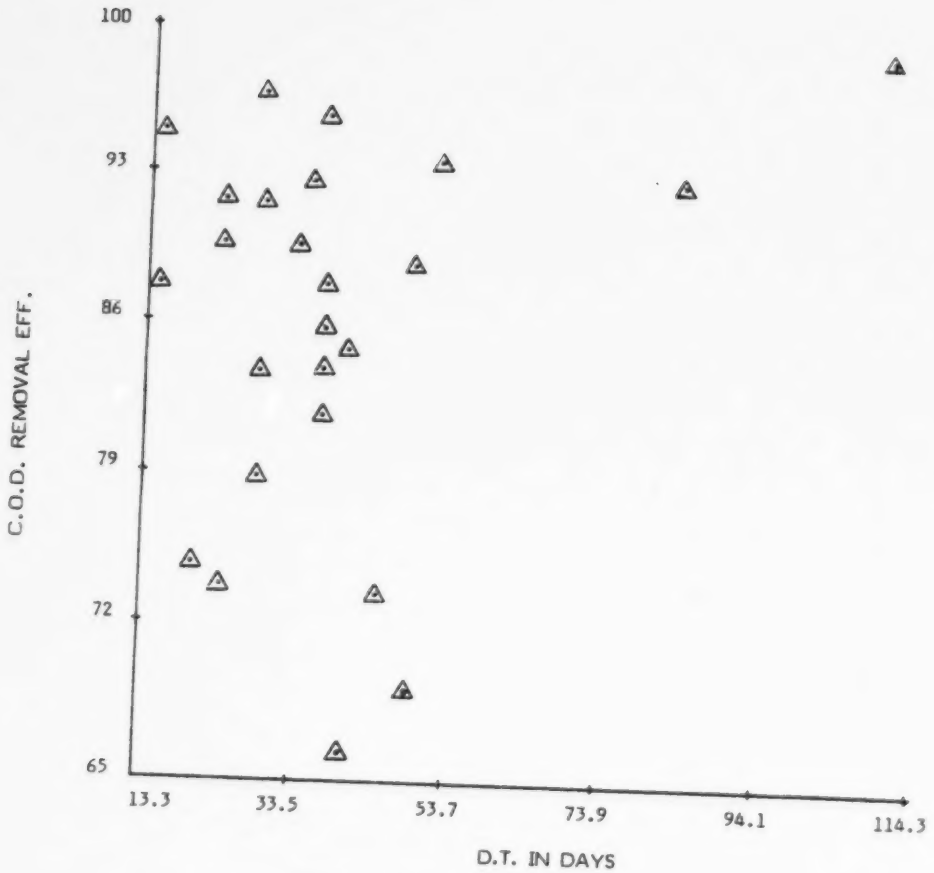
S.S. REMOVAL EFF. = $39.54 + 1.02(DT) - 0.0047(DT)^2$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-10 EFFECT OF DETENTION TIME ON SUSPENDED SOLIDS REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DT	39.462	21.195	4.420	111.111	16.461	94.650
COD	87.123	8.269	1.724	98.390	66.792	31.598

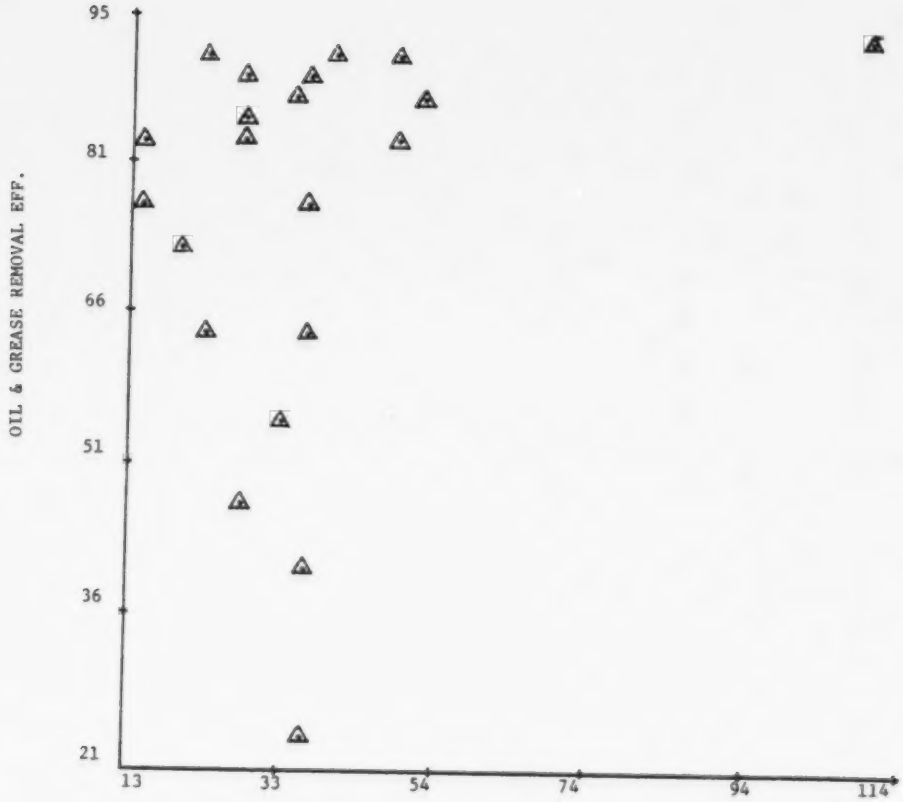
C.O.D. REMOVAL EFF. = $96.26 - 0.448\ (DT) + 0.0043\ (DT)^2$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-11 EFFECT OF DETENTION TIME ON C.O.D. REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
O & G	74.372	18.539	4.046	91.787	25.000	66.787
D.T.	37.179	19.562	4.269	111.111	16.461	94.650

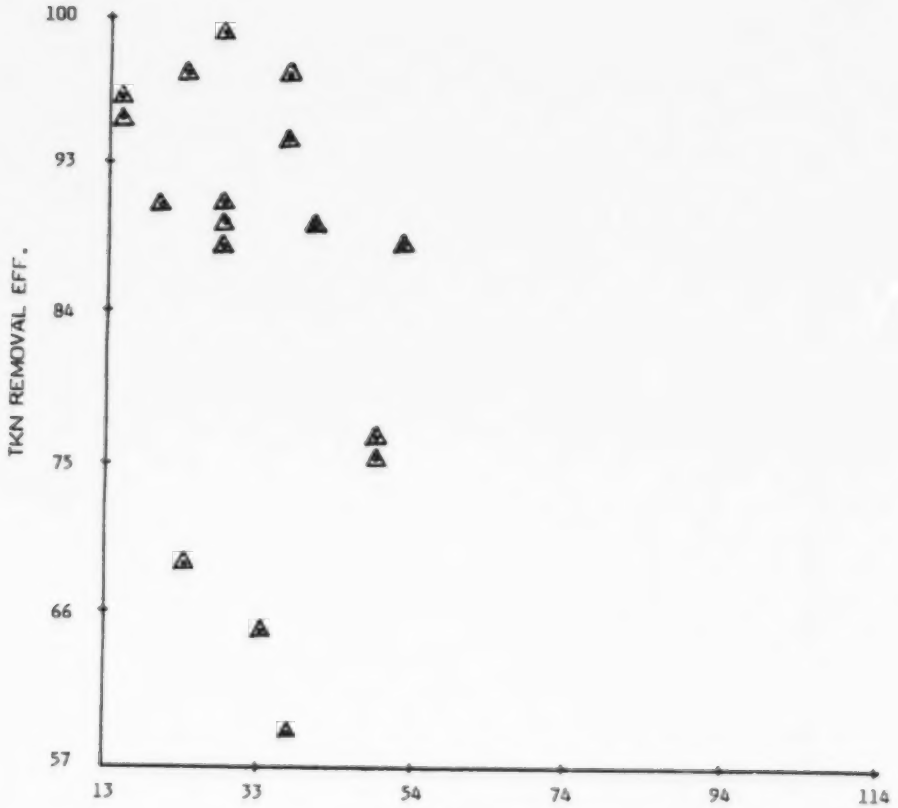
OIL & GREASE REMOVAL EFF. = $139.4 - 5.1(D.T.) + 0.1(D.T.)^2 - 0006(D.T.)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-12 EFFECT OF DETENTION TIME ON OIL & GREASE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TKN	86.221	11.899	2.805	99.620	59.524	40.096
DT	37.300	21.212	5.000	111.111	16.461	94.650

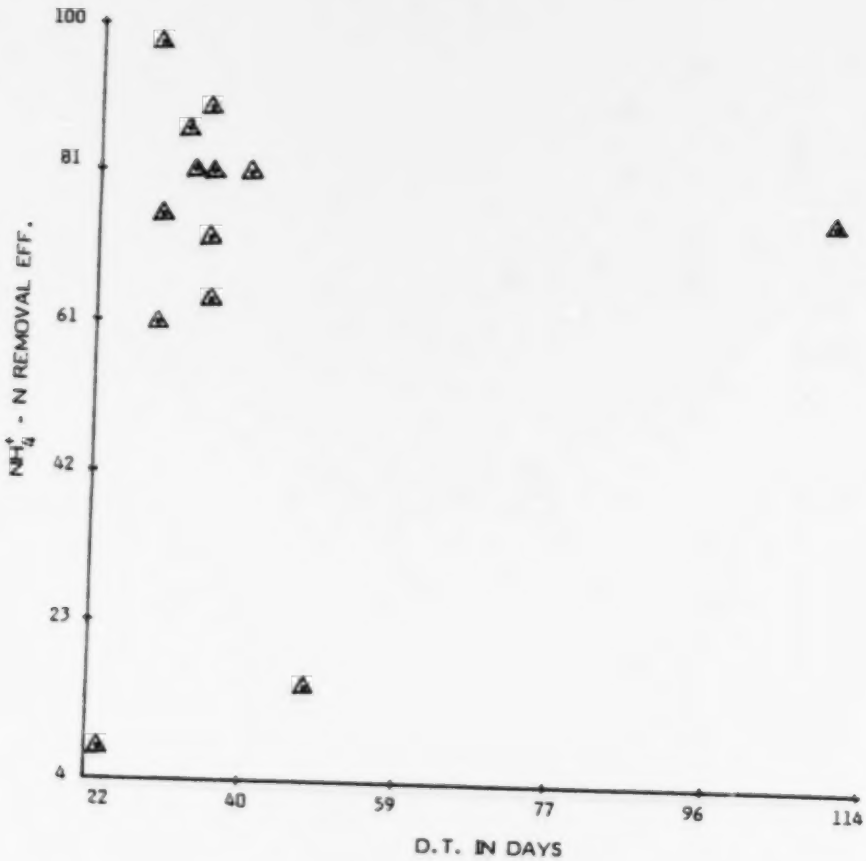
TKN REMOVAL EFF. = $115.6 - 1.6(DT) + 0.02(DT)^2 - 0.00009(DT)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-13 EFFECT OF DETENTION TIME ON TOTAL KJELDAHL NITROGEN REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
NH_4^+-N	69.477	25.382	6.554	95.062	8.333	86.728
D.T.	42.243	20.652	5.332	111.111	24.691	86.420

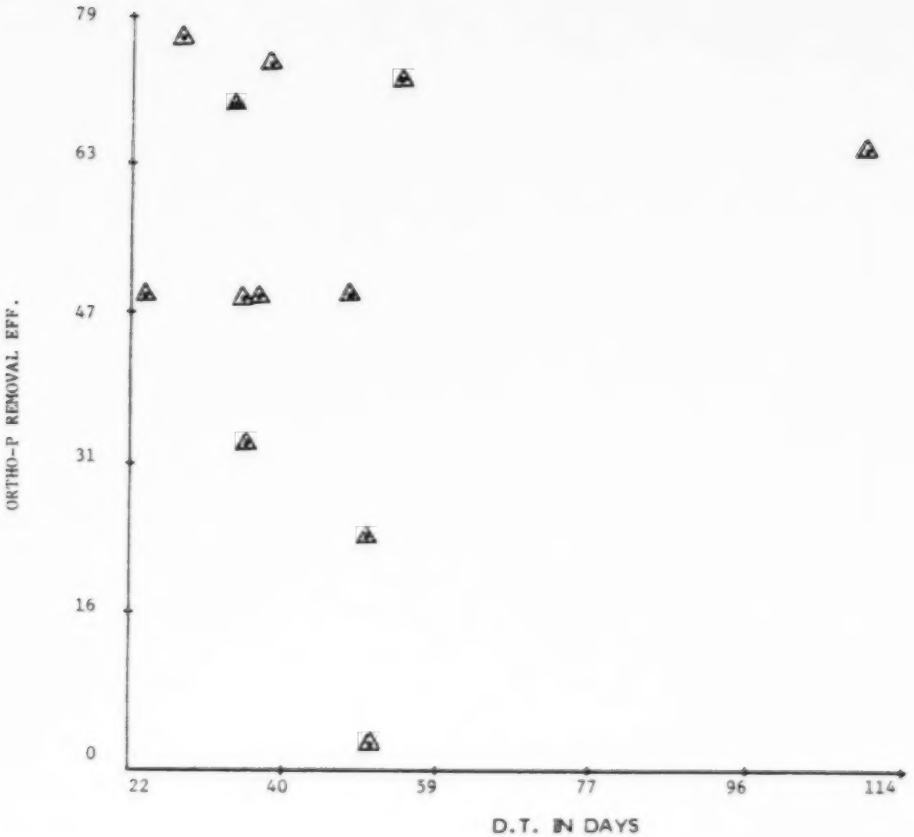
NH_4^+-N REMOVAL EFF = -408 + 29.6(D.T.) - 0.55(D.T.)^2 + 0.003(D.T.)^3

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE 8-14 EFFECT OF DETENTION TIME ON AMMONIA REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
ORTHO-P	51.916	21.392	6.765	75.000	3.750	71.250
D.T.	45.524	24.443	7.729	111.111	25.000	86.111

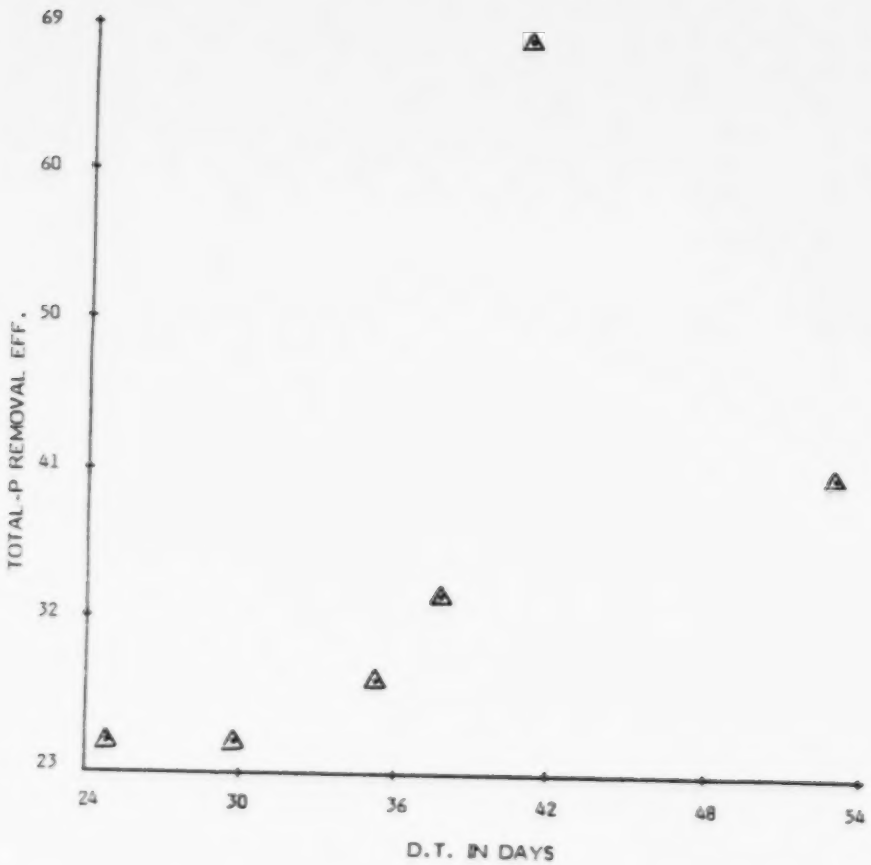
ORTHO-P REMOVAL EFF. = $-142 + 14.5(D.T.) - 0.3(D.T.)^2 + 0.002(D.T.)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-15 EFFECT OF DETENTION TIME ON ORTHO-PHOSPHATE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TOTAL-P	36.657	15.872	6.480	66.667	25.000	41.667
D.T.	36.779	9.565	3.905	52.632	25.000	27.632

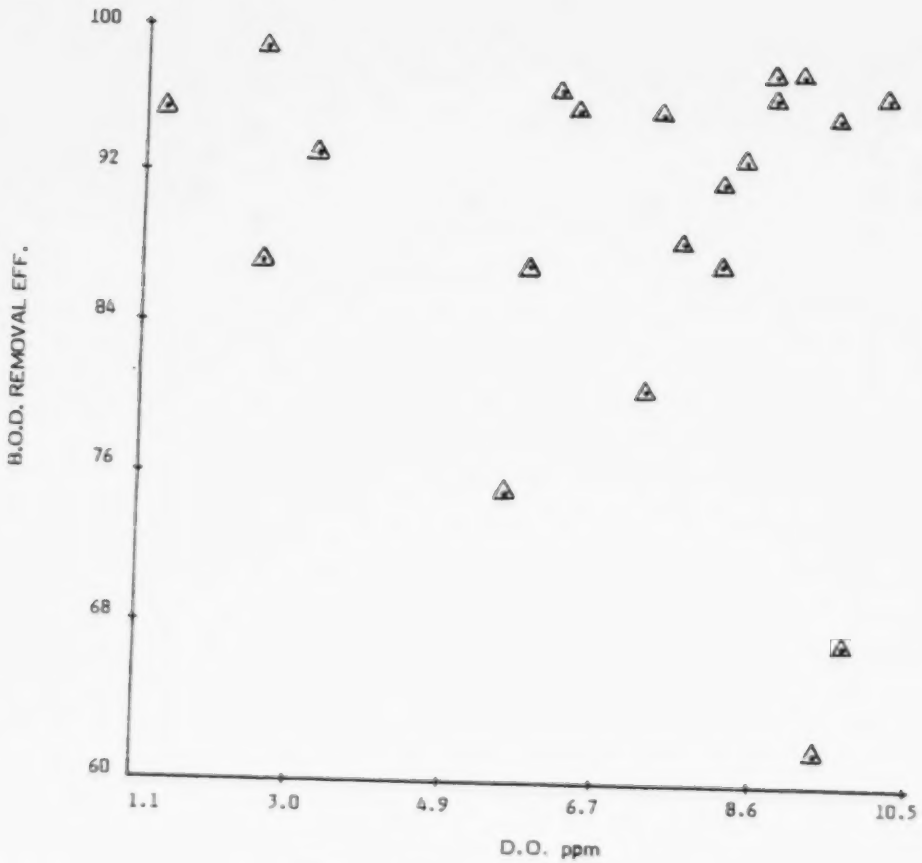
TOTAL-P REMOVAL EFF. = $1035 - 88.5(D.T.) + 2.5(D.T.)^2 - 0.022(D.T.)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-16 EFFECT OF DETENTION TIME ON TOTAL-PHOSPHATE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DO	6.909	2.801	0.584	10.200	1.400	8.800
BOD	89.657	9.881	2.060	98.570	62.025	36.545

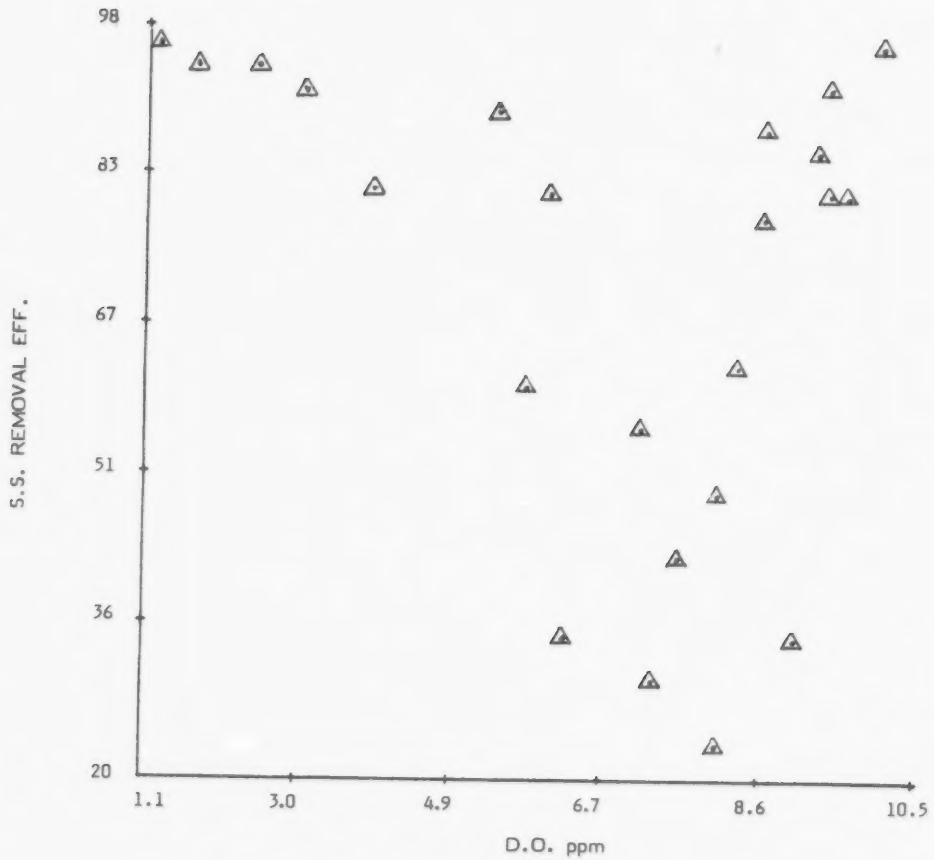
B.O.D. REMOVAL EFF. = $95.46 - 0.965\ (DO) + 0.0156\ (DO)^2$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-17 EFFECT OF DISSOLVED OXYGEN ON B.O.D. REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DO	6.090	2.801	0.584	10.200	1.400	8.800
SS	70.470	23.874	4.978	94.444	24.000	70.444

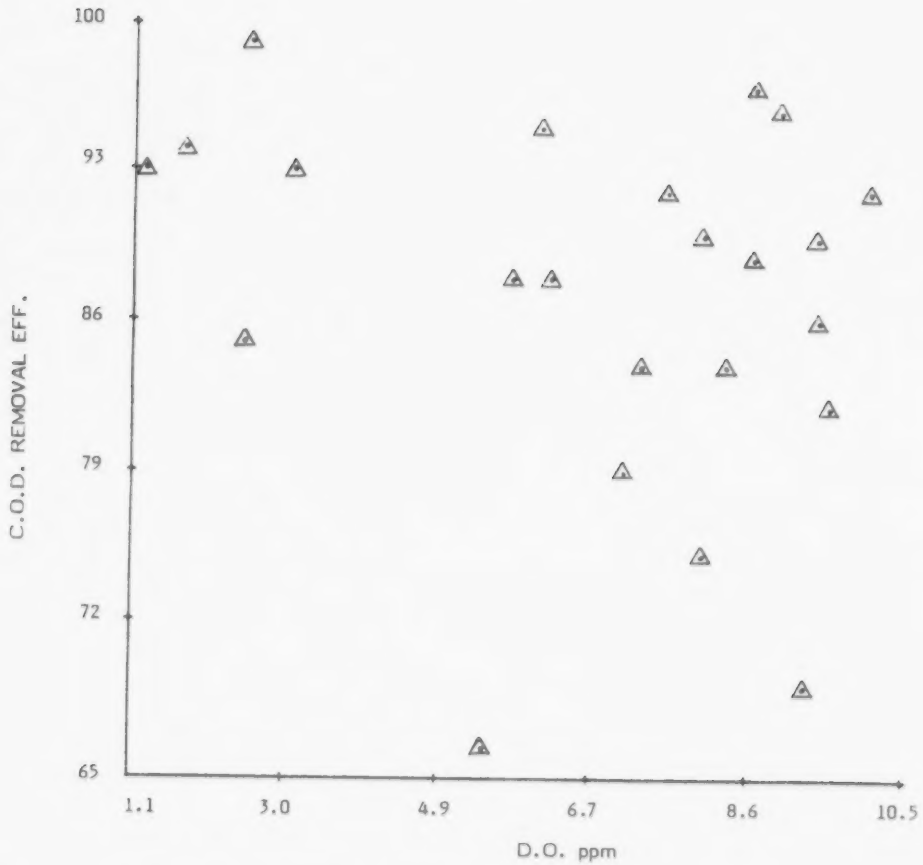
S.S. REMOVAL EFF. = $144.6 - 27.7\ (DO) + 2.1\ (DO)^2$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-18 EFFECT OF DISSOLVED OXYGEN ON SUSPENDED SOLIDS REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DO	6.909	2.801	0.584	10.200	1.400	8.800
COD	87.123	8.269	1.724	98.390	66.792	31.598

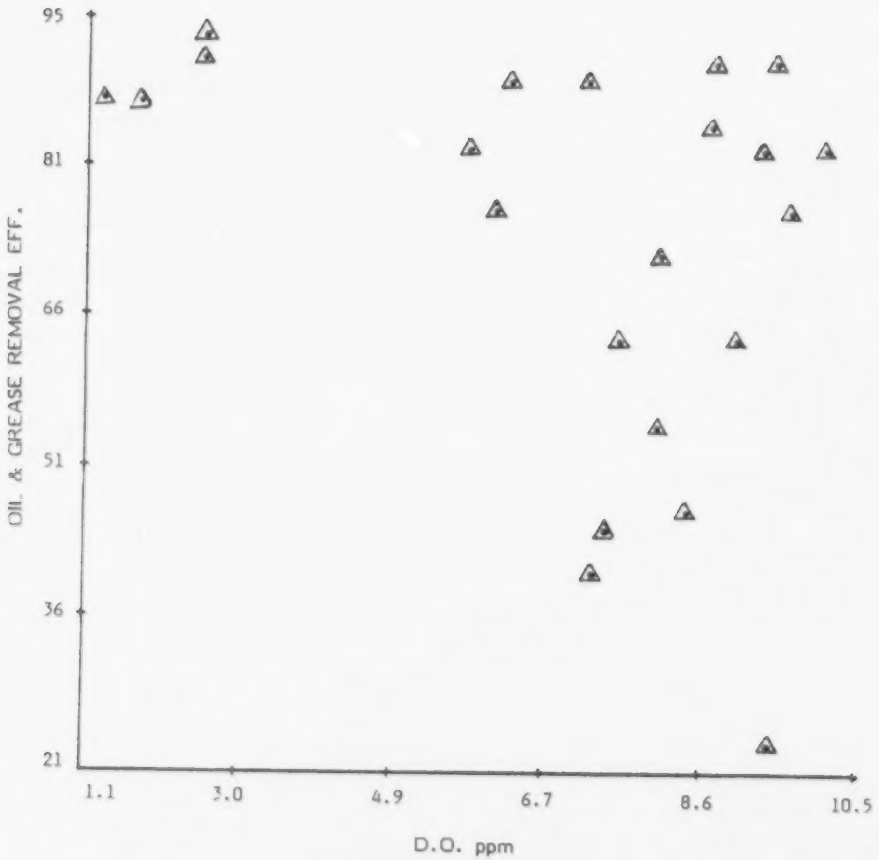
C.O.D. REMOVAL EFF. = $100.5 - 4.58\ (DO) + 0.33\ (DO)^2$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE 8-19 EFFECT OF DISSOLVED OXYGEN ON C.O.D. REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
O & G	74.372	18.539	4.046	91.787	25.000	67.787
D.O.	7.148	2.792	0.609	10.200	1.400	8.800

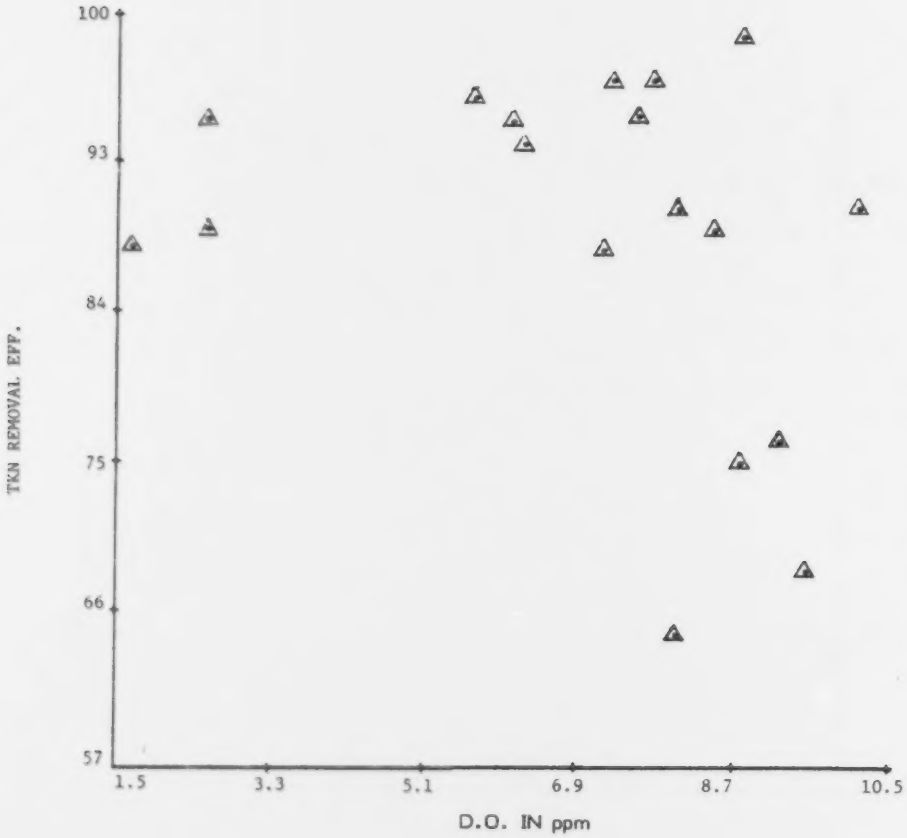
OIL & GREASE REMOVAL EFF. = $54 + 28.9(DO) - 6.3(DO)^2 + 0.4(DO)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-20 EFFECT OF DISSOLVED OXYGEN ON OIL AND GREASE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TOTAL-P	86.221	11.899	2.805	99.620	59.524	40.096
D.O.	7.178	2.536	0.598	10.200	1.800	8.400

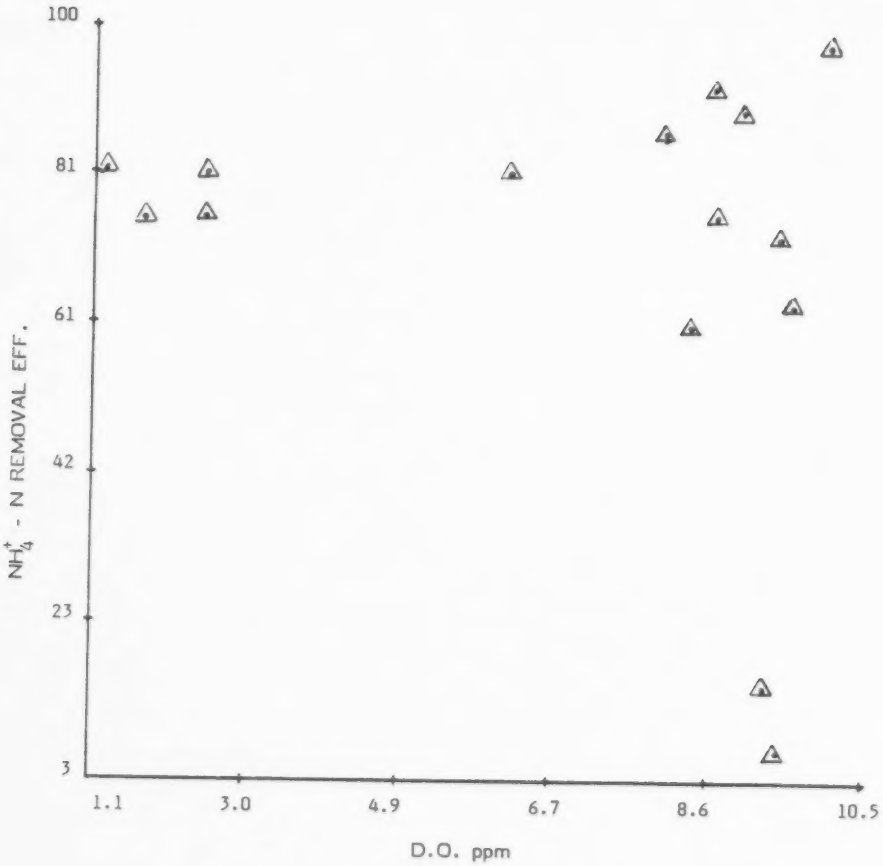
TOTAL-P REMOVAL EFF. = $45.3 + 30(D.O.) - 4.9(D.O.)^2 + 0.23(D.O.)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-21 EFFECT OF DISSOLVED OXYGEN ON TOTAL KJELDAHL NITROGEN REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
NH_4^+ - N	69.477	25.382	6.554	95.062	8.333	86.728
DO	7.160	3.290	0.850	10.200	1.400	8.800

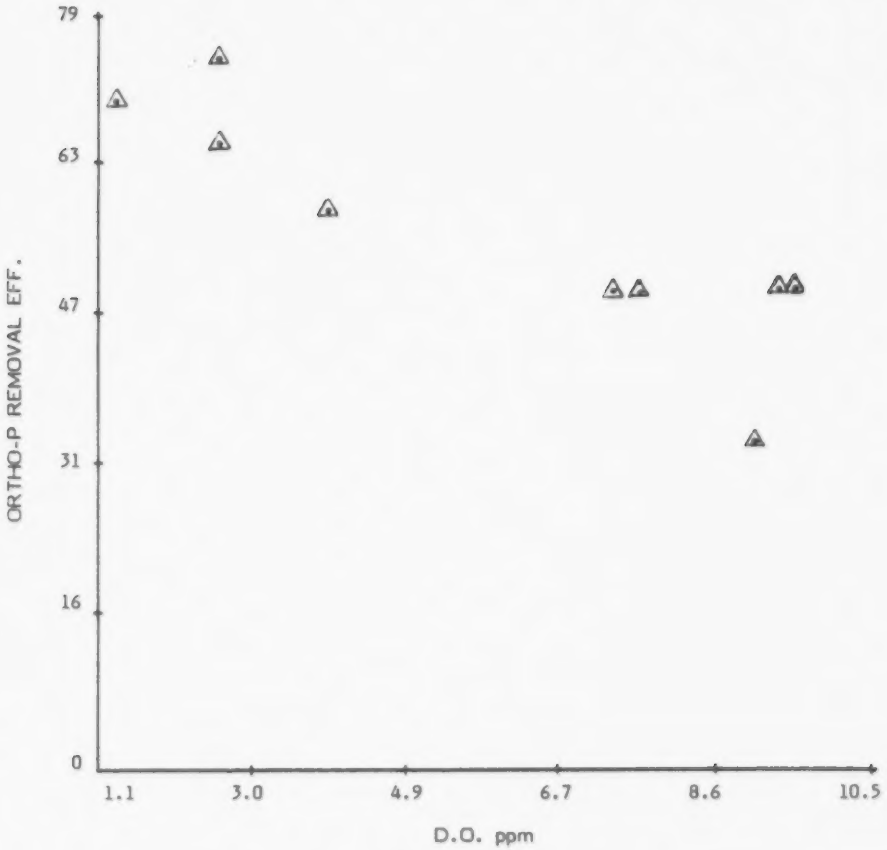
NH_4^+ - N REMOVAL EFF. = $61 + 10.4\ (DO) - 1.4\ (DO)^2 + 0.03\ (DO)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

FIGURE B-22 EFFECT OF DISSOLVED OXYGEN ON AMMONIA REMOVAL EFFICIENCY FOR FULL SCALE PLANT

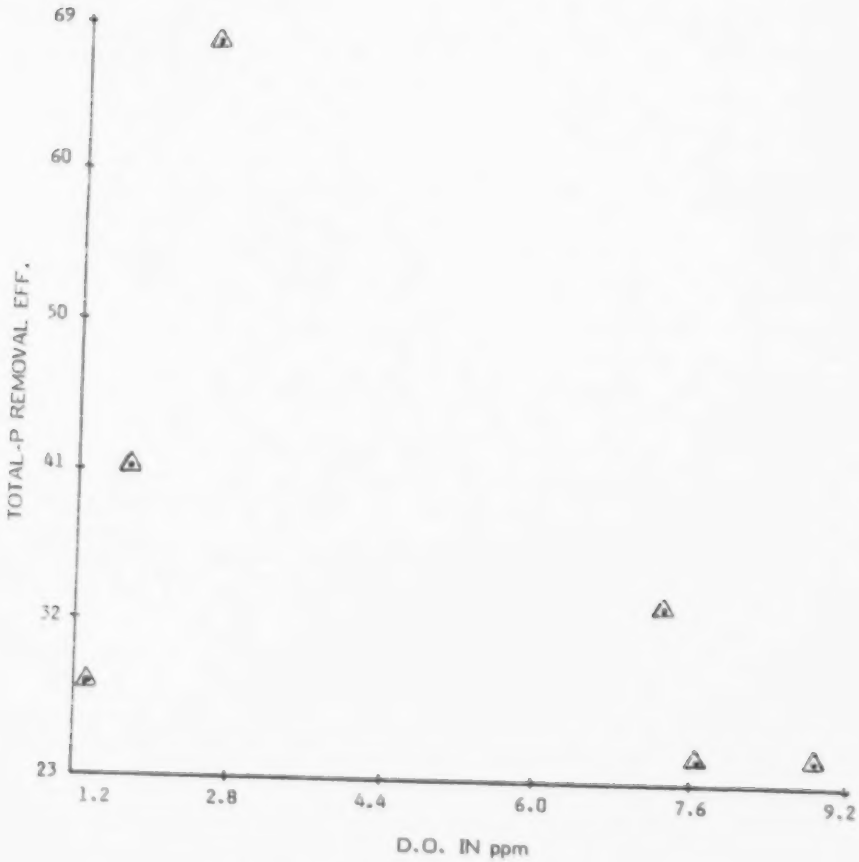


	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
ORTHO-P	51.916	21.392	6.765	75.000	3.750	71.250
DO	6.210	3.649	1.154	10.200	1.400	8.800

ORTHO-P REMOVAL EFF. = $-16 + 53(DO) - 10(DO)^2 + 0.6(DO)^3$

OVERFLOW RATE
MEAN = 40 gpd/ft^2
STANDARD DEVIATION = 37 gpd/ft^2

FIGURE 8-23 EFFECT OF DISSOLVED OXYGEN ON ORTHO-PHOSPHATE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TOTAL-P	36.657	15.872	6.480	66.667	25.000	41.667
D.O.	4.983	3.399	1.388	8.900	1.400	7.500

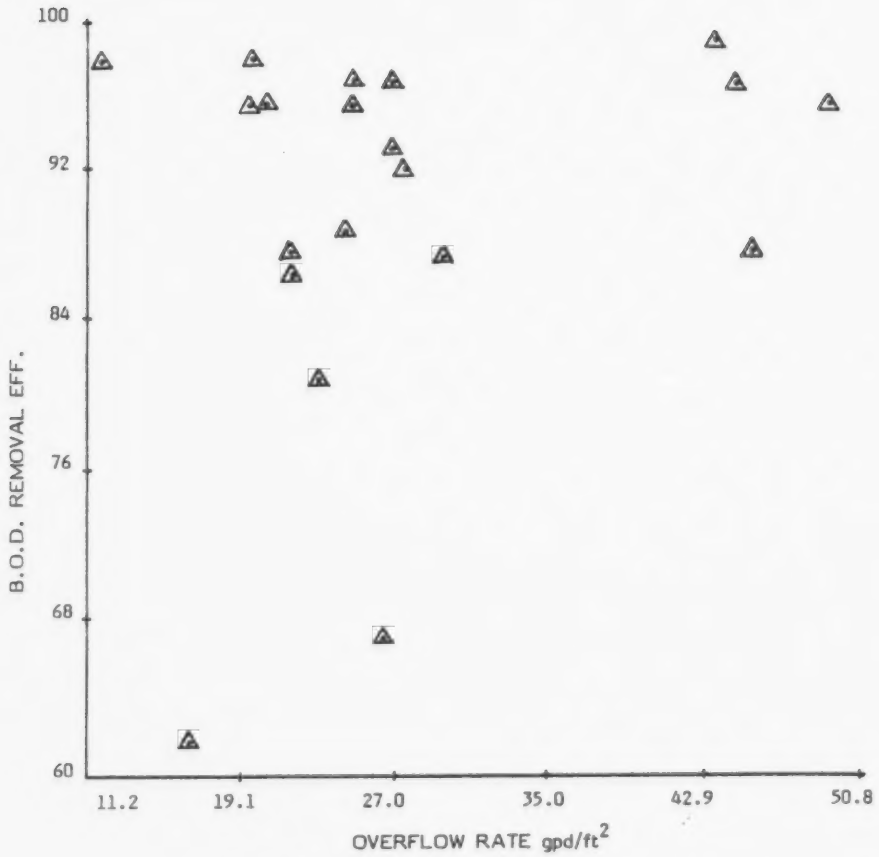
TOTAL-P REMOVAL EFF. = $-66 + 88.5(DO) - 17(DO)^2 + 0.92(DO)^3$

OVERFLOW RATE

MEAN = 40 gpd/ft^2

STANDARD DEVIATION = 37 gpd/ft^2

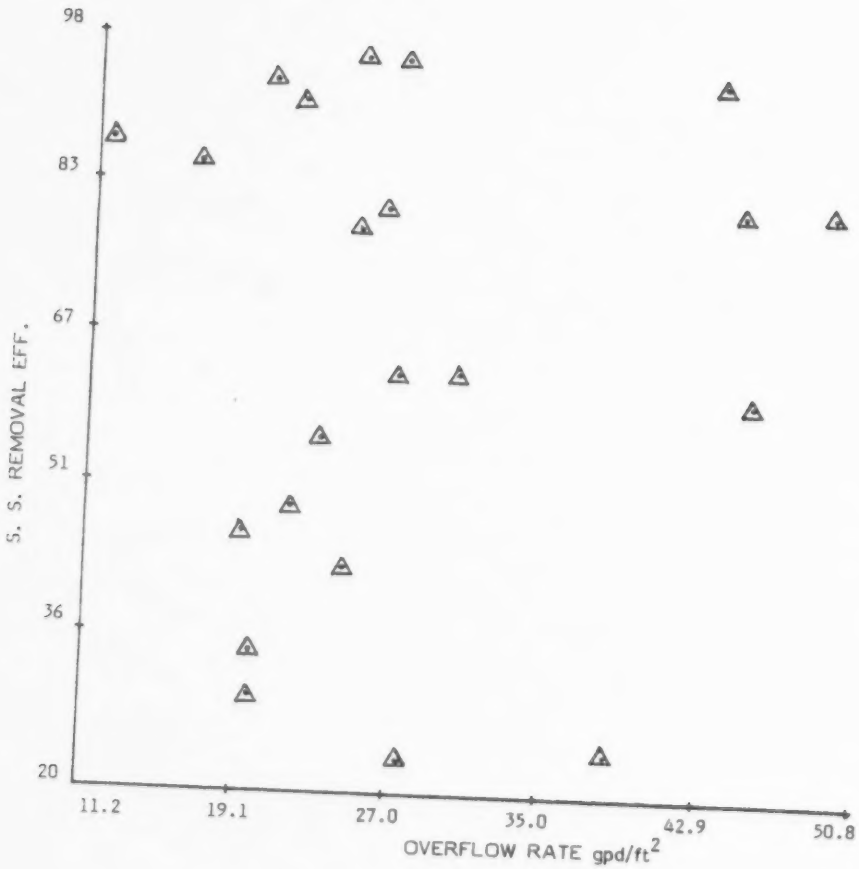
FIGURE 8-24 EFFECT OF DISSOLVED OXYGEN ON TOTAL-PHOSPHATE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
BOD	90.199	9.803	2.139	98.570	62.025	36.545
OF RATE	27.537	10.159	2.217	49.592	12.398	37.194

$$\text{B.O.D. REMOVAL EFF.} = 104 - 1.9(\text{OF RATE}) + 0.07(\text{OF RATE})^2 - 0.0007\ (\text{OF RATE})^3$$

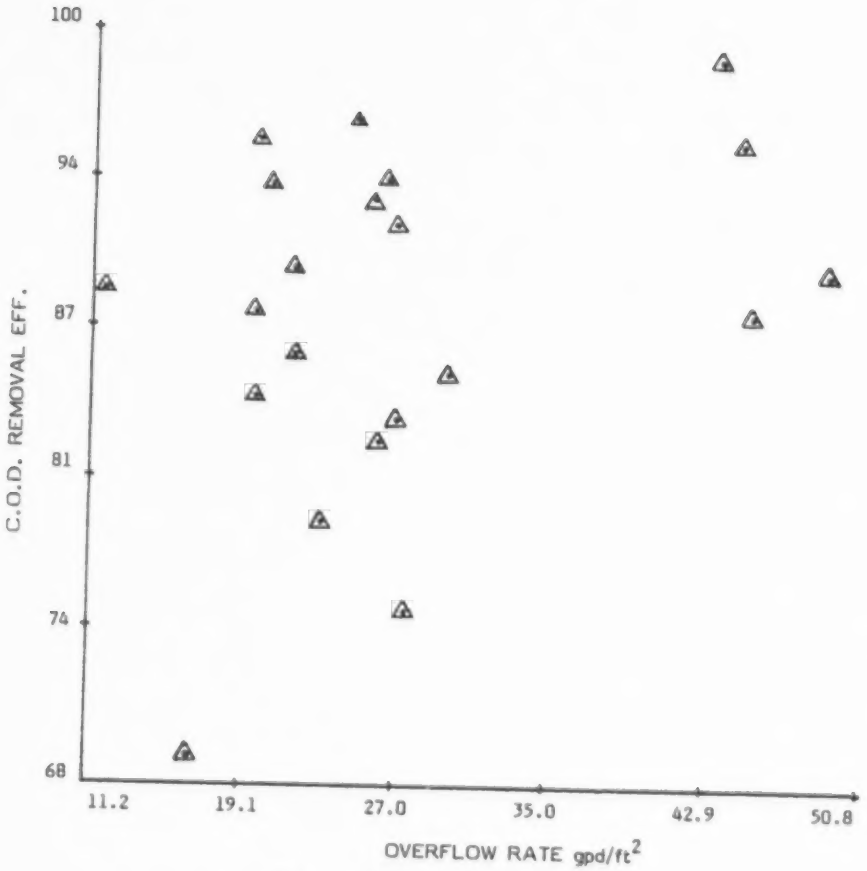
FIGURE B-25 EFFECT OF OVERFLOW RATE ON BIOCHEMICAL OXYGEN DEMAND REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
S.S.	68.667	24.239	5.289	94.444	24.000	70.444
OF RATE	27.537	10.159	2.217	49.592	12.398	37.194

S. S. REMOVAL EFF. = 225 - 18.8(OF RATE) + 0.67(OF RATE)^2 - 0.007(OF RATE)^3

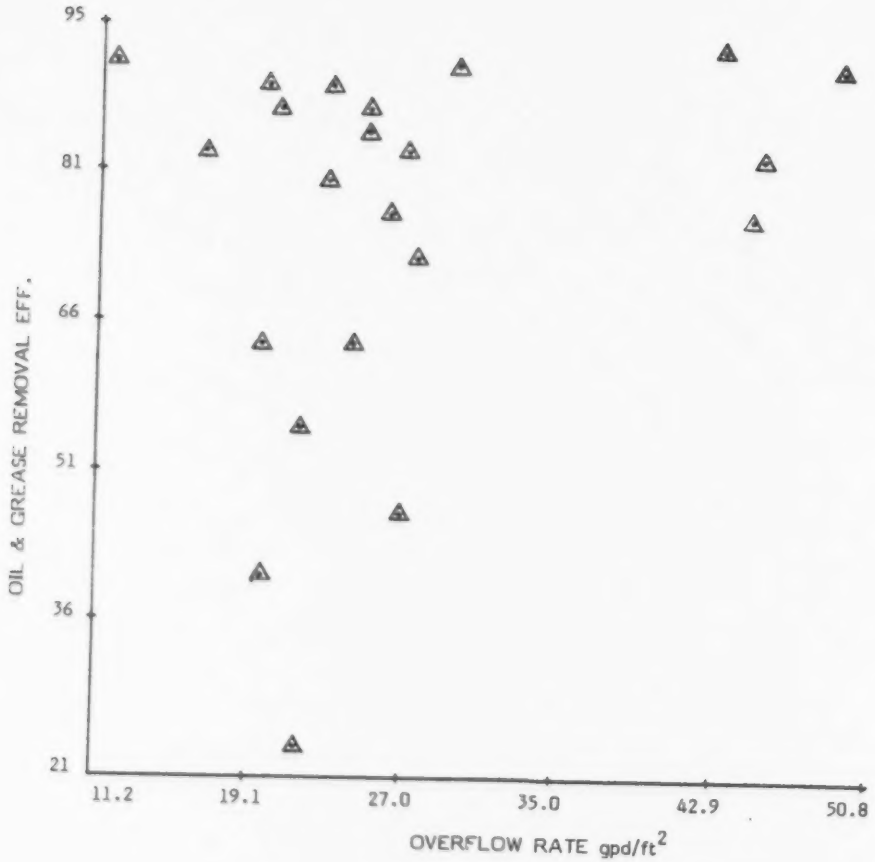
FIGURE B-26 EFFECT OF OVERFLOW RATE ON SUSPENDED SOLIDS REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
COD	87.840	7.253	1.583	98.390	69.244	29.146
OF RATE	27.537	10.159	2.217	49.592	12.398	37.194

C.O.D. REMOVAL EFF. = 85 - 0.15 (OF RATE) + 0.01 (OF RATE)^2 -0.0001 (OF RATE)^3

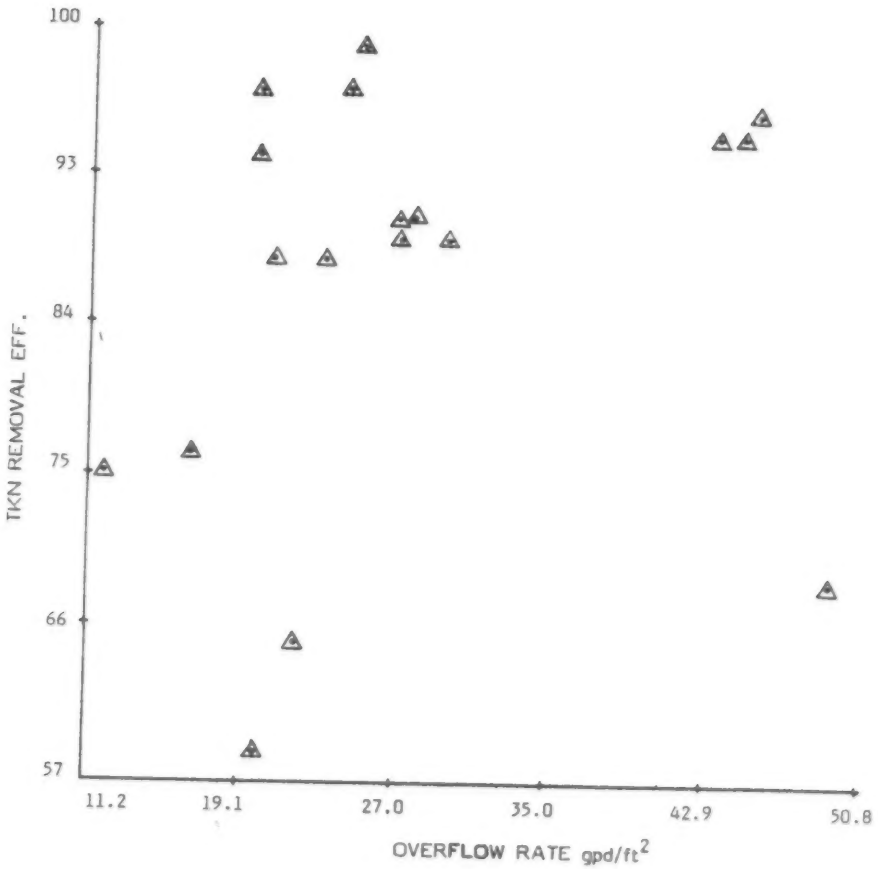
FIGURE 8-27 EFFECT OF OVERFLOW RATE ON CHEMICAL OXYGEN DEMAND REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
O & G	74.372	18.539	4.046	91.787	25.000	66.787
OF RATE	27.537	10.159	2.217	49.5923	12.398	37.194

OIL & GREASE REMOVAL EFF. = 192 - 13.6(OF RATE) + 0.5(OF RATE)^2 - 0.005(OF RATE)^3

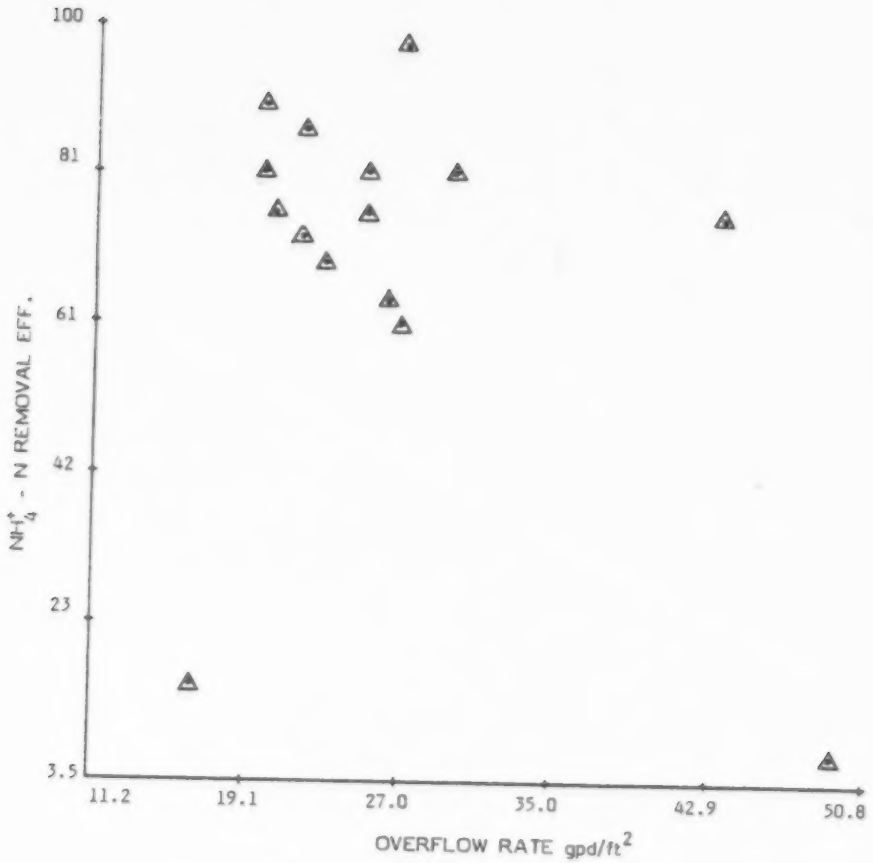
FIGURE B-28 EFFECT OF OVERFLOW RATE ON OIL & GREASE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TKN	86.221	11.899	2.805	99.620	59.524	40.096
OF RATE	28.030	10.910	2.571	49.592	12.398	37.194

TKN REMOVAL EFF. = 117 - 6.4(OF RATE) + 0.31(OF RATE)^2 - 0.004(OF RATE)^3

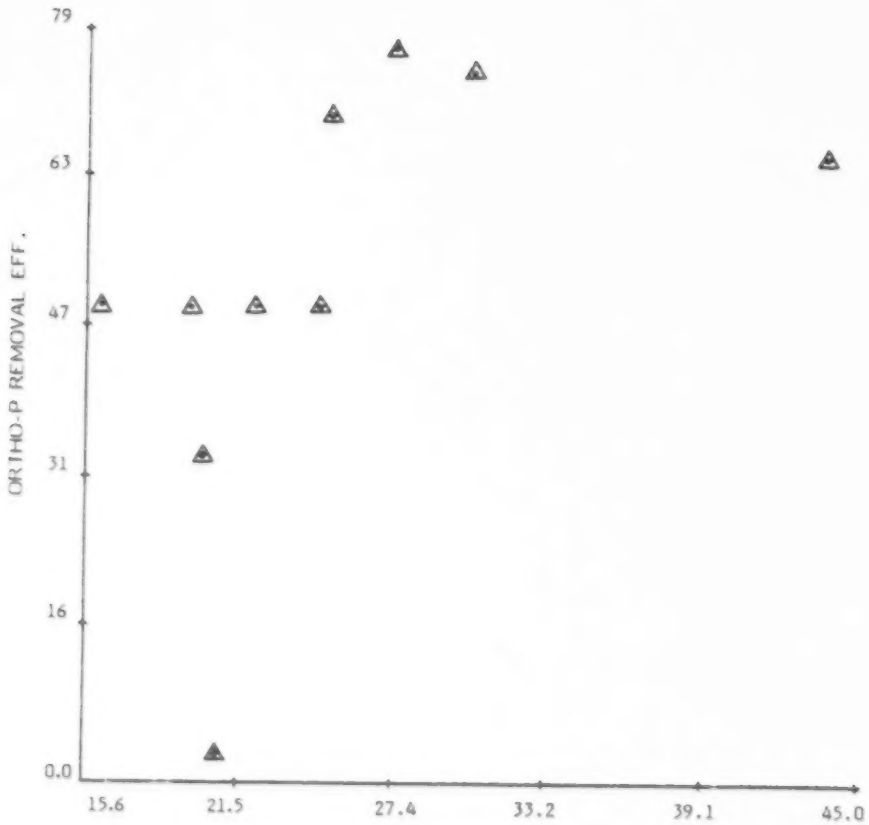
FIGURE 8-29 EFFECT OF OVERFLOW RATE ON TOTAL KJELDAHL NITROGEN REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
NH_4^+-N	69.477	25.382	6.554	95.062	8.333	86.728
OF RATE	26.059	9.651	2.492	49.592	12.398	37.194

NH_4^+ - N REMOVAL EFF. = 218 - 20.2(OF RATE) + 0.8(OF RATE)^2 - 0.01(OF RATE)^3

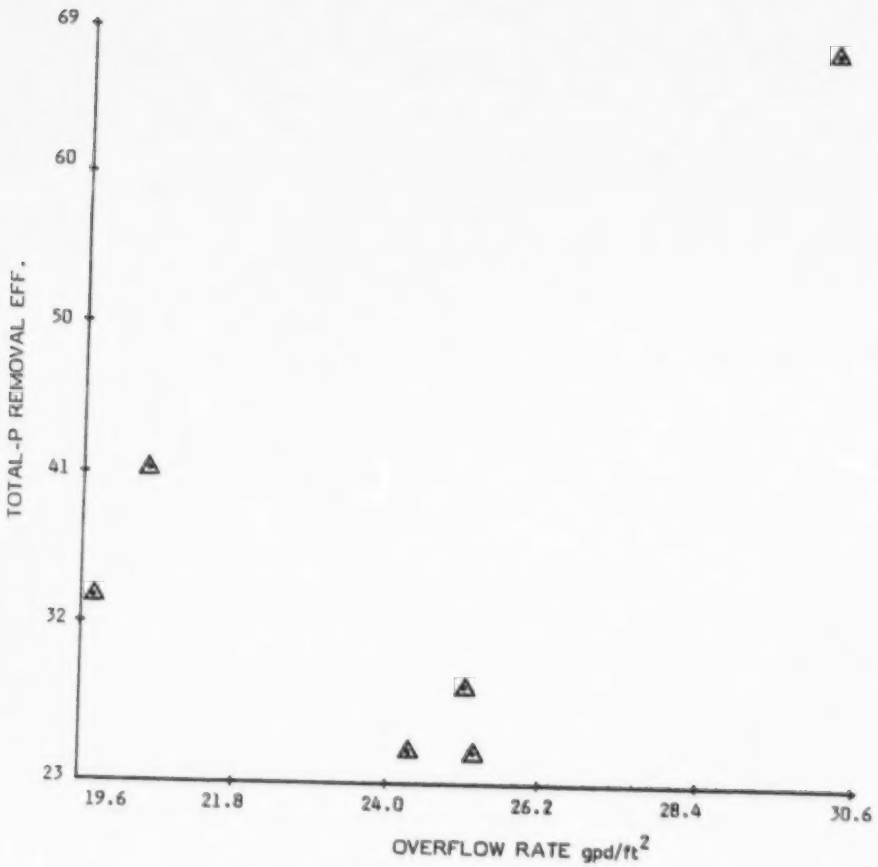
FIGURE B-30 EFFECT OF OVERFLOW RATE ON AMMONIA REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
ORTHO-P	51.916	21.392	6.765	75.000	3.750	71.250
OF RATE	25.124	7.782	2.461	44.082	16.531	27.551

ORTHO-P REMOVAL EFF. = 516 - 59.2(OF RATE) + 2.3(OF RATE)^2 - 0.03(OF RATE)^3

FIGURE B-31 EFFECT OF OVERFLOW RATE ON ORTHO-PHOSPHATE REMOVAL EFFICIENCY FOR FULL SCALE PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TOTAL-P	36.657	15.872	6.480	66.667	25.000	41.667
OF RATE	24.354	3.745	1.529	30.306	19.969	10.338

TOTAL-P REMOVAL EFF. = $-3277 + 424.7(\text{OF RATE}) - 18(\text{OF RATE})^2 + 0.25(\text{OF RATE})^3$

FIGURE B-32 EFFECT OF OVERFLOW RATE ON TOTAL PHOSPHATE REMOVAL EFFICIENCY FOR FULL SCALE PLANT

APPENDIX C

EFFECTS OF OPERATING CONDITIONS ON TREATMENT EFFICIENCIES DURING PILOT PLANT OPERATION

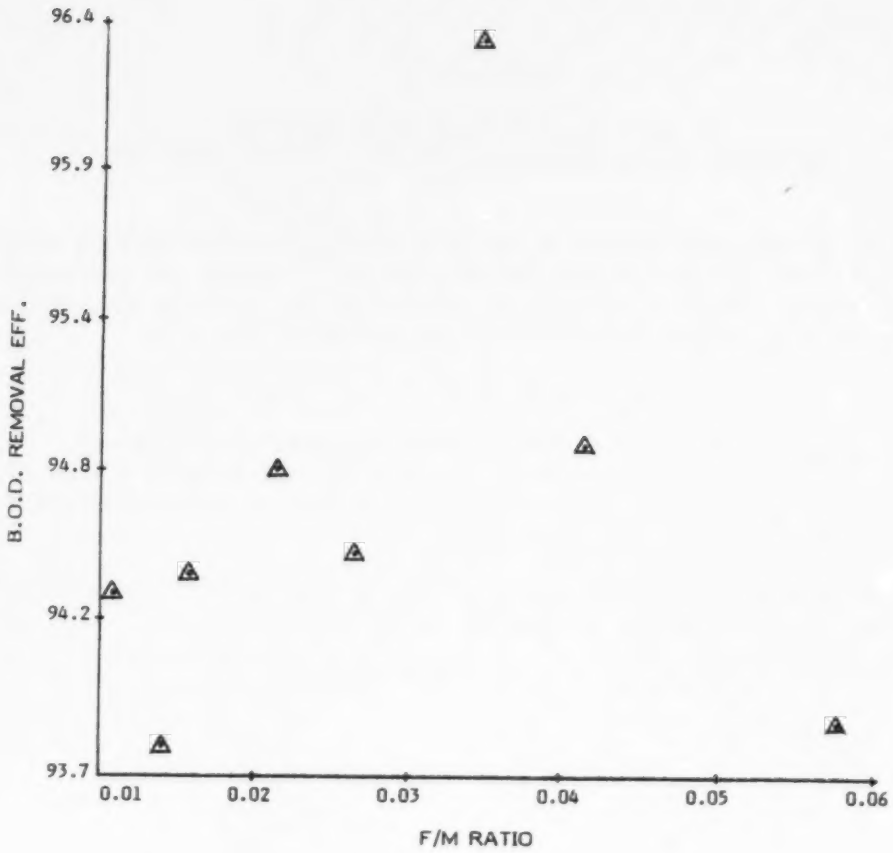
The statistical analysis herein is to utilize the equation derived from polynomial regression to demonstrate the relationship between two variables. Polynomial regression is a statistical technique for finding the coefficients b_o, b_1, b_2 ---- b_m in the functional relationship of the form

$$Y = b_o + b_1X + b_2X^2 + \text{----} + b_mX^m$$

between a dependent variable Y and a single independent variable X. Powers of an independent variable are generated to calculate polynomials of successively increasing degrees. For the discussion here, a polynomial regression of degree of 3 is chosen.

The results during pilot plant operation are presented in Figures C-1 through Figure C-32. The conversion of gpd/ft^2 is as follows:

$$1 \text{ gpd/ft}^2 = 4.73 \times 10^{-4} \text{ liter/sec/m}^2$$



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
F/M	0.032	0.015	0.005	0.061	0.016	0.045
B.O.D.	94.639	0.771	0.273	96.311	93.845	2.466

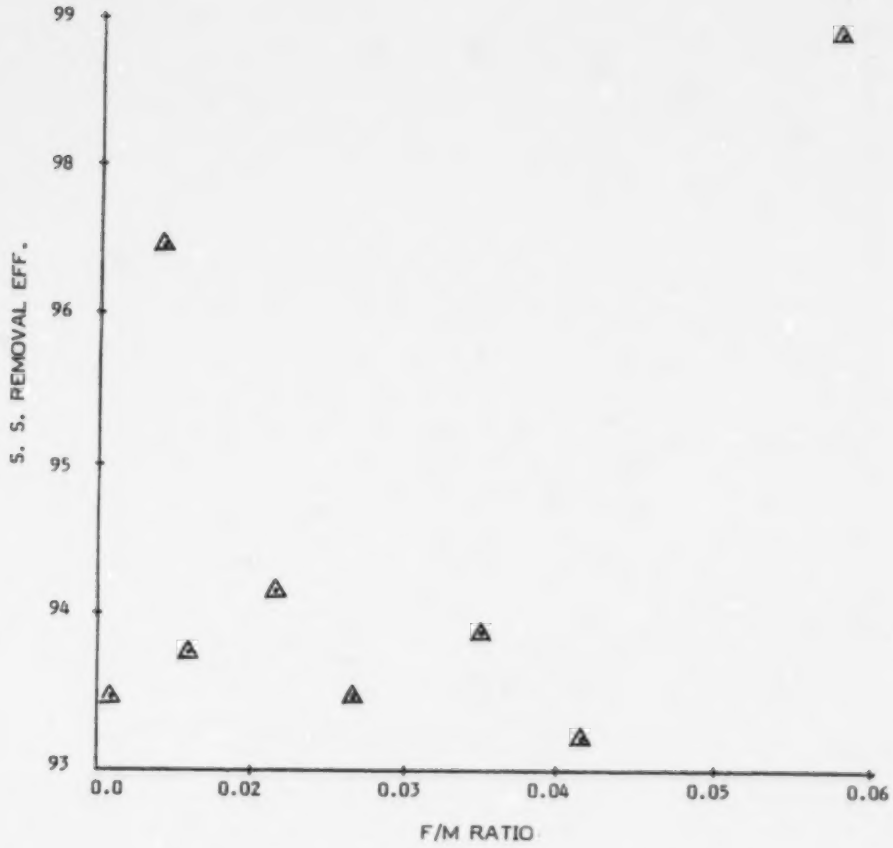
B.O.D. REMOVAL EFF. = $44.98 + 399(F/M) - 1099(F/M)^2 + 813(F/M)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-1 EFFECT OF F/M RATIO ON B.O.D. REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
F/M	0.287	0.236	0.046	0.863	0.037	0.827
S. S.	68.296	28.261	5.543	98.690	7.895	90.795

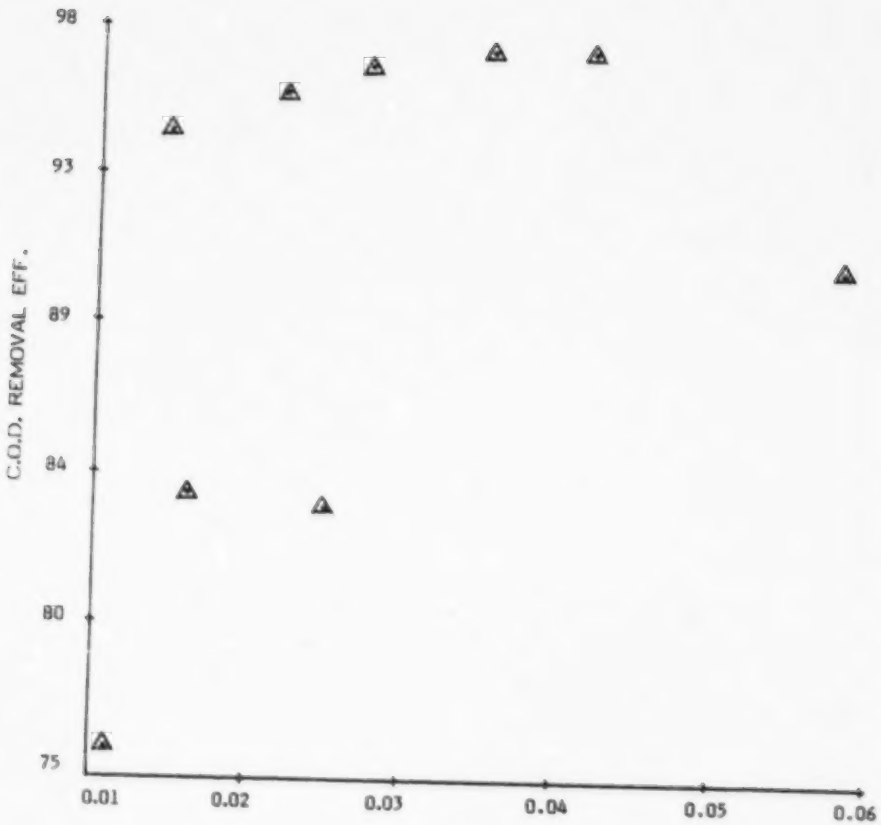
S. S. REMOVAL EFF. = $46 + 314(F/M) - 940(F/M)^2 + 735(F/M)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-2 EFFECT OF F/M RATIO ON SUSPENDED SOLIDS REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
F/M	0.032	0.015	0.005	0.061	0.016	0.045
C.O.D.	89.775	7.583	2.681	96.804	76.512	20.292

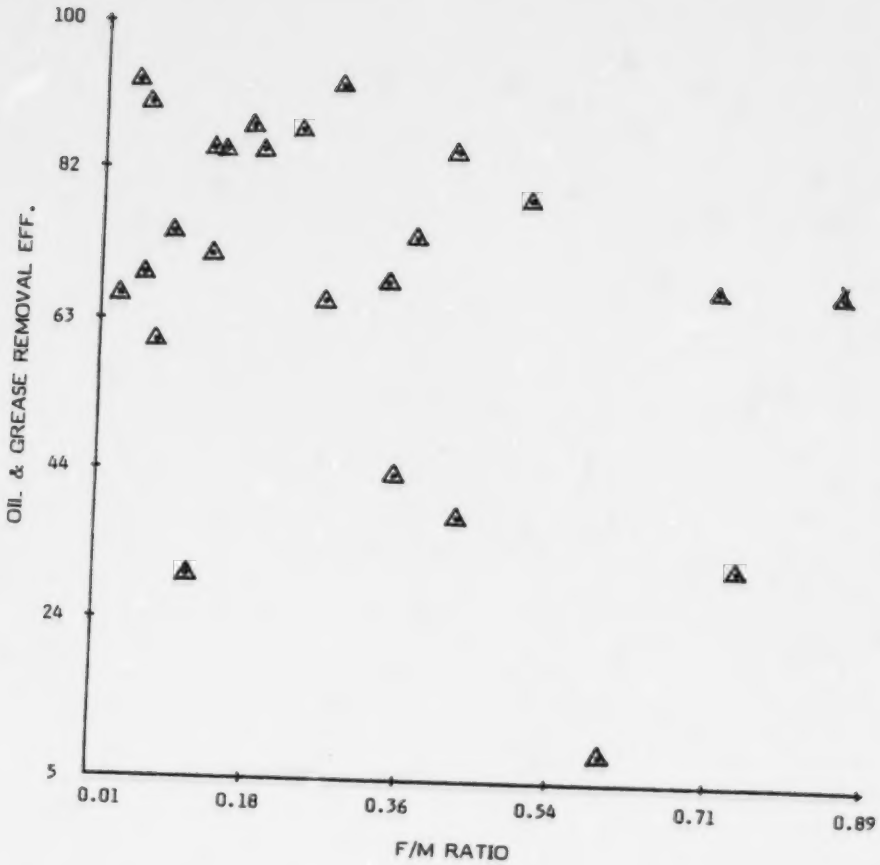
C.O.D. REMOVAL EFF. = $49.6 + 281(F/M) - 724(F/M)^2 + 522\ (F/M)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-3 EFFECT OF F/M RATIO ON C.O.D. REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
O & G	68.805	21.264	4.092	96.248	10.000	86.248
F/M	0.298	0.239	0.046	0.863	0.037	0.827

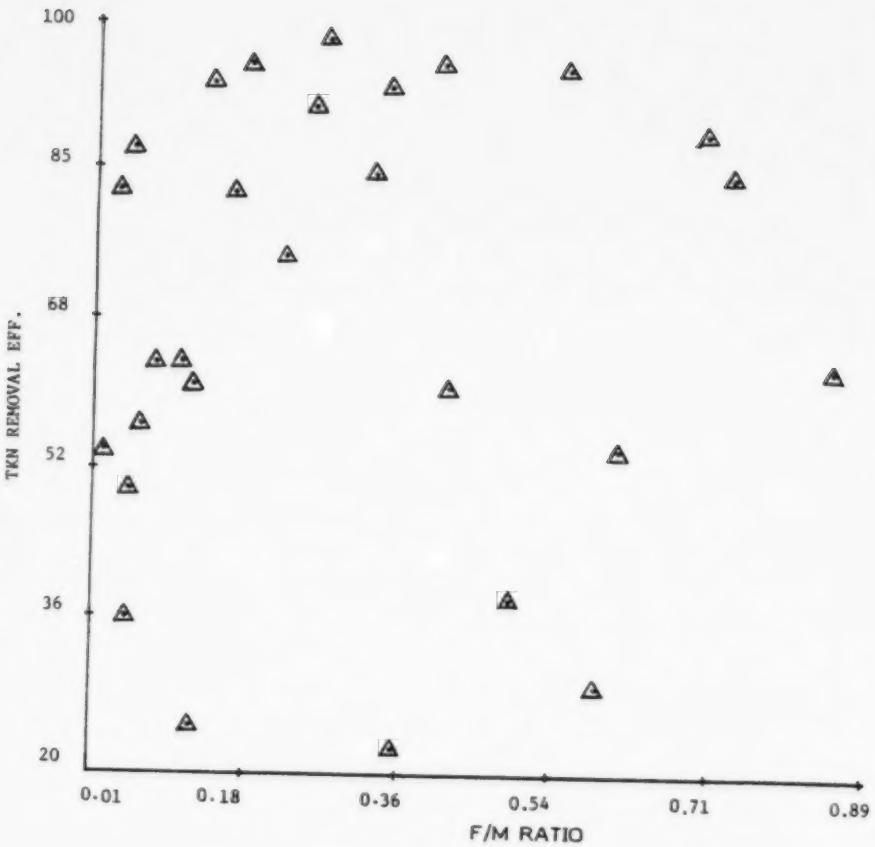
O & G REMOVAL EFF. = $65 + 140(F/M) - 488(F/M)^2 + 374(F/M)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-4 EFFECT OF F/M RATIO ON OIL AND GREASE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TKN	69.531	23.489	4.520	97.083	23.810	73.274
F/M	0.298	0.239	0.046	0.863	0.037	0.827

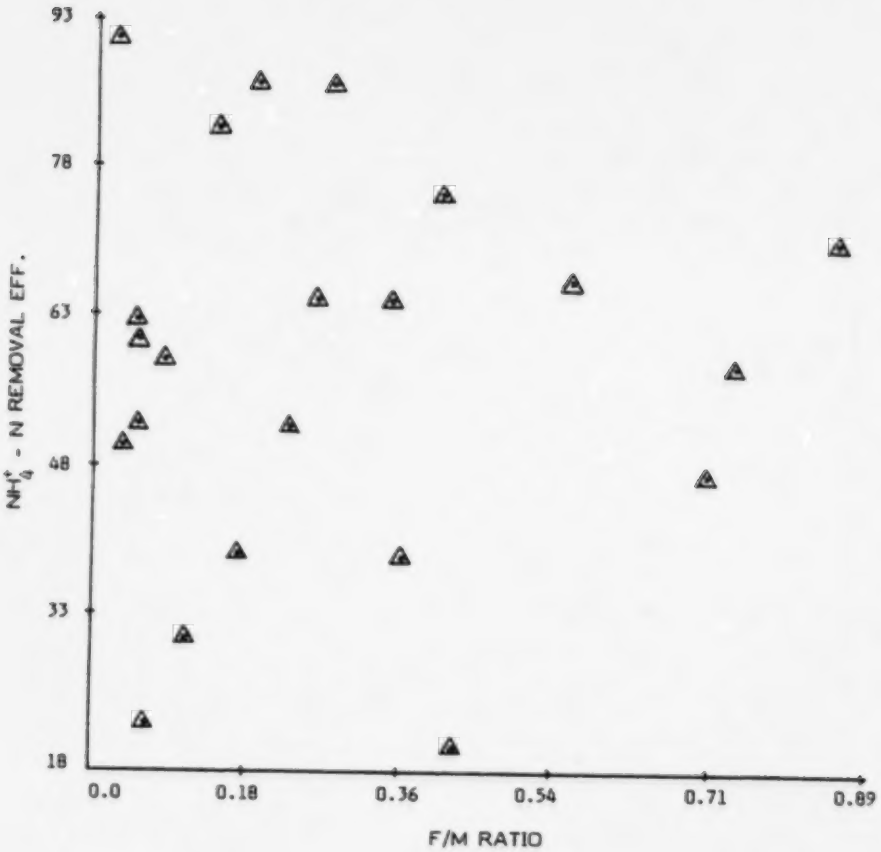
TKN REMOVAL EFF. = $49 + 233(F/M) - 595(F/M)^2 + 422(F/M)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-5 EFFECT OF F/M ON TOTAL KJELDAHL NITROGEN REMOVAL EFFICIENCY FOR PILOT PLANT

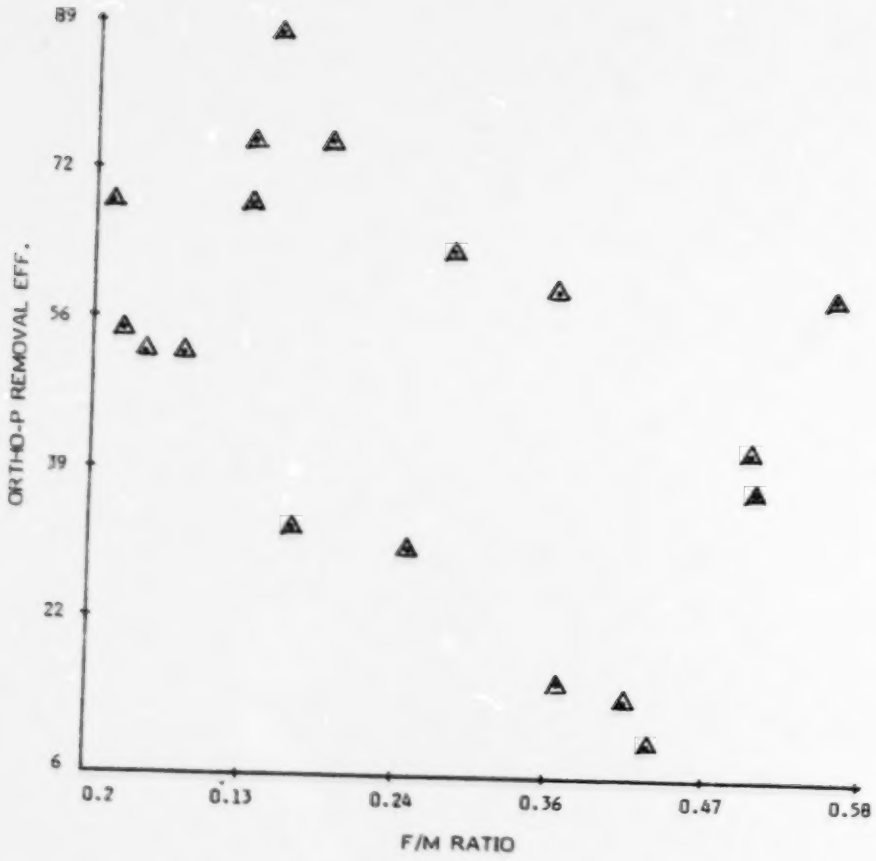


	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
NH_4^+ -N	58.342	19.404	4.137	89.091	21.622	67.469
F/M	0.288	0.248	0.053	0.863	0.037	0.827

NH_4^+ - N REMOVAL EFF. = $52.9 + 84.9(F/M) - 285(F/M)^2 + 242(F/M)^3$

OVERFLOW RATE
MEAN = 349 gpd/ft^2
STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-6 EFFECT OF F/M RATIO ON AMMONIA REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
ORTHO-P	49.261	22.487	5.454	84.687	10.000	74.687
F/M	0.248	0.167	0.041	0.565	0.037	0.528

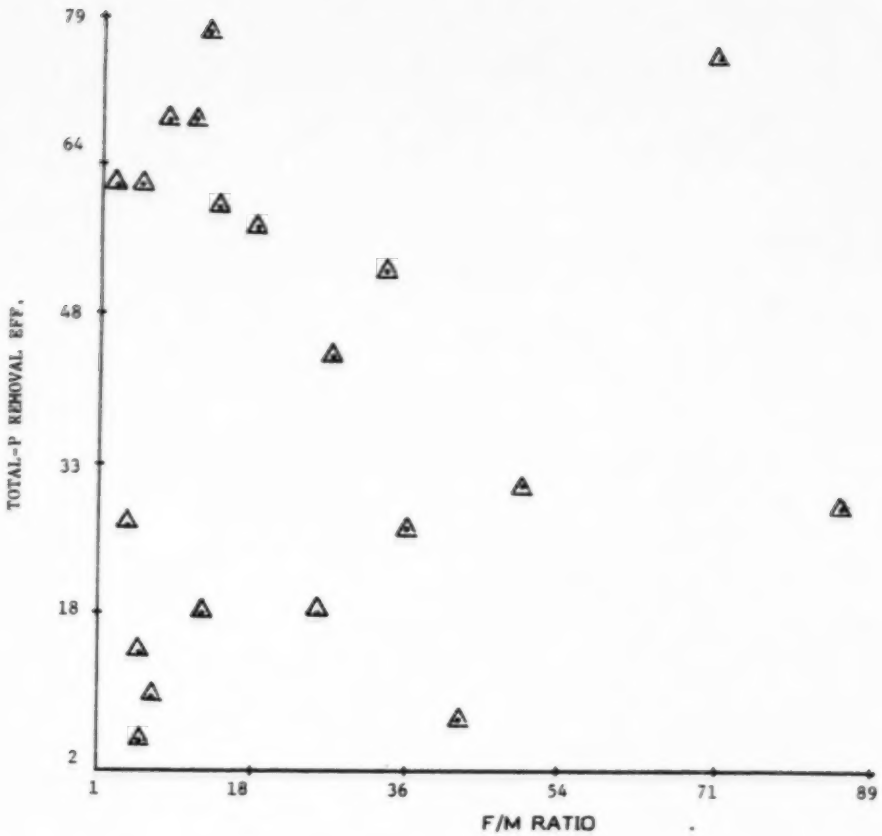
ORTHO-P REMOVAL EFF. = $36.3 + 520(F/M) - 2{,}635(F/M)^2 + 3{,}147(F/M)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-7 EFFECT ON F/M RATIO ON ORTHO-PHOSPHATE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TOTAL-P	40.199	23.536	5.263	75.000	6.250	68.750
F/M	0.247	0.232	0.052	0.863	0.037	0.827

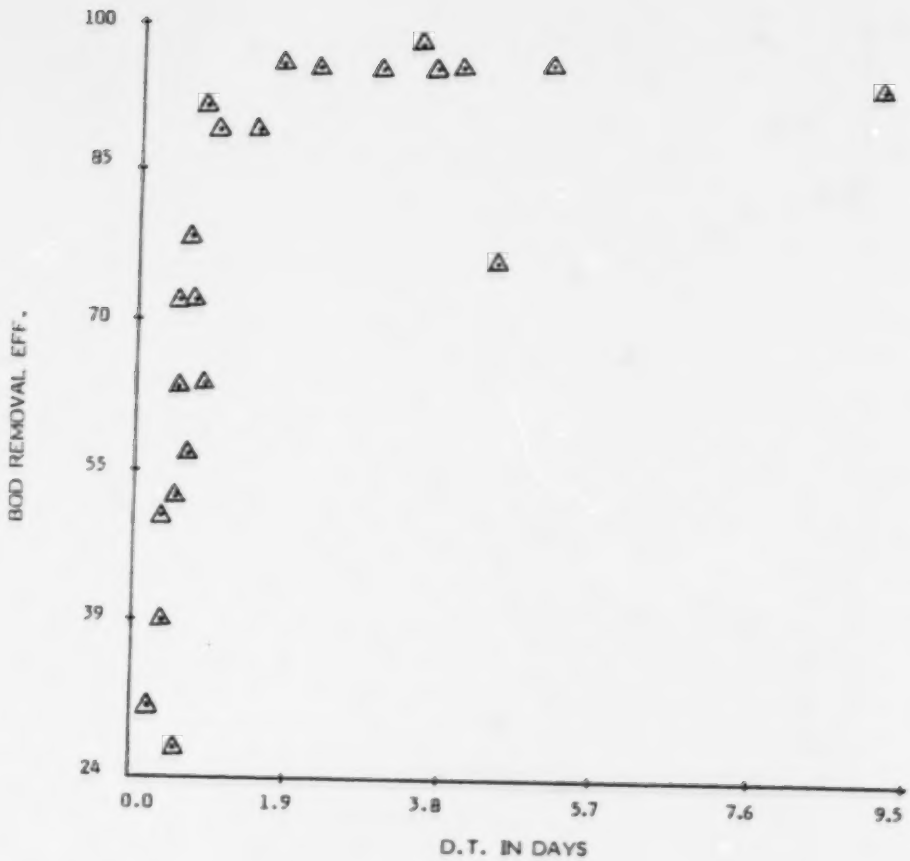
TOTAL-P REMOVAL EFF. = $39 + 28.2(F/M) - 109(F/M)^2 + 96.3(F/M)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-8 EFFECT OF F/M RATIO ON TOTAL-PHOSPHATE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DT	2.094	2.073	0.407	9.188	0.305	8.883
BOD	75.899	21.416	4.200	96.311	27.941	68.370

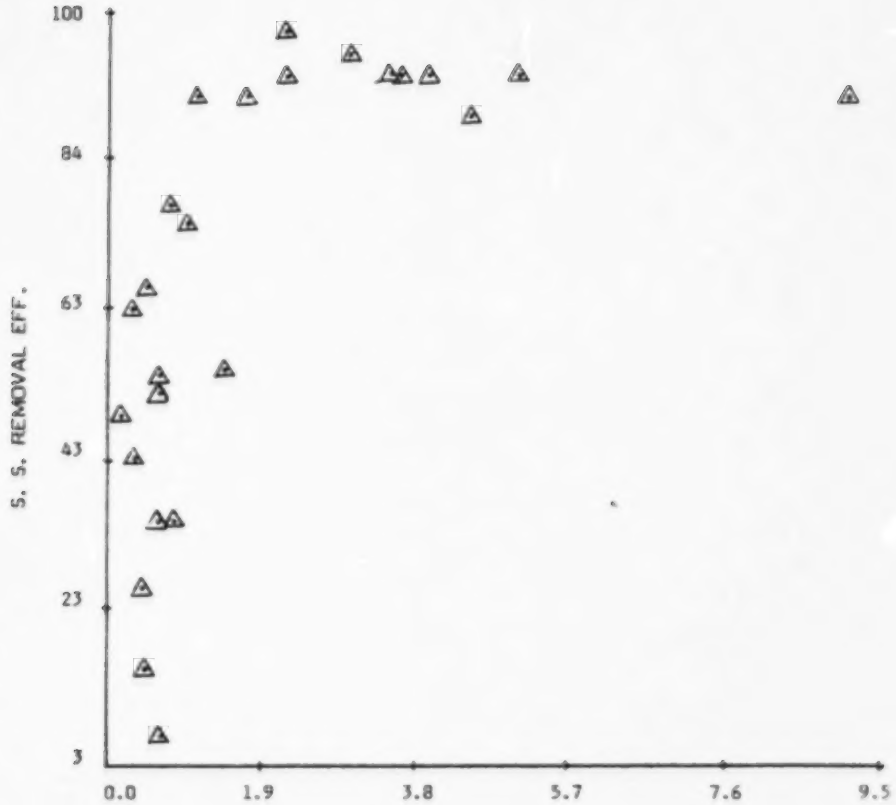
$$\text{BOD REMOVAL EFF.} = 26.4 + 61.9\,(DT) - 15.4\,(DT)^2 + 1.0\,(DT)^3$$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-9 EFFECT OF DETENTION TIME ON BOD REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DT	2.121	2.055	0.403	9.188	0.305	8.883
SS	68.296	28.261	5.543	98.690	7.895	90.795

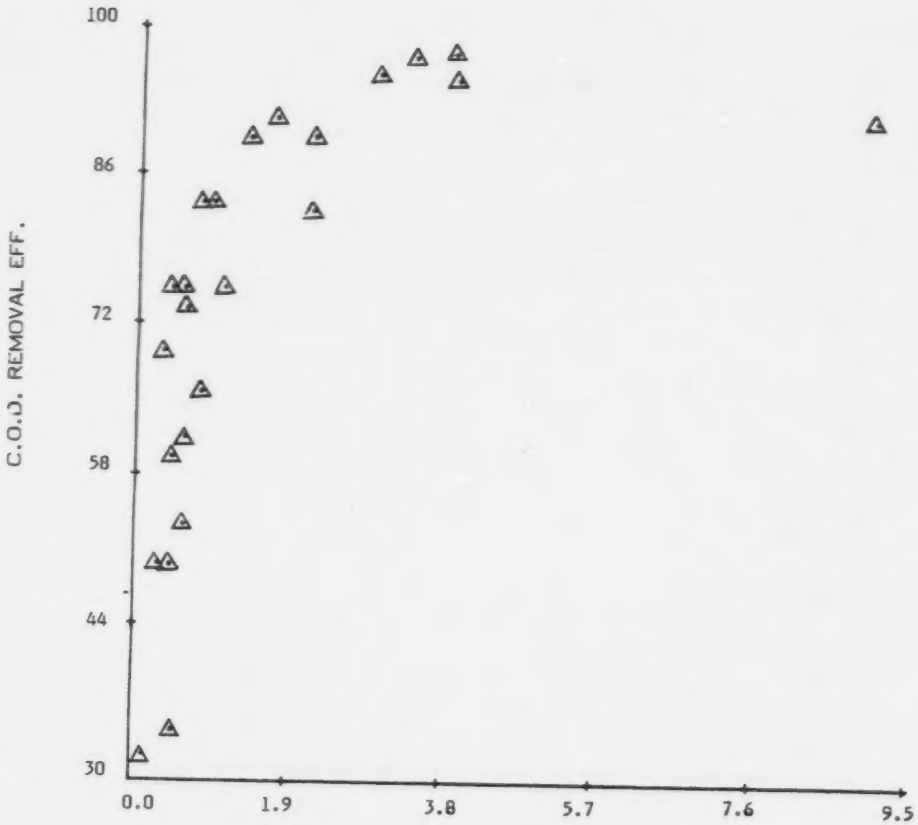
S.S. REMOVAL EFF. = $16.2 + 54.4\ (DT) - 11.5\ (DT)^2 + 0.7\ (DT)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-10 EFFECT OF DETENTION TIME ON SUSPENDED SOLIDS REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DT	2.061	2.040	0.393	9.188	0.305	8.883
COD	74.564	18.099	3.483	96.804	33.562	63.242

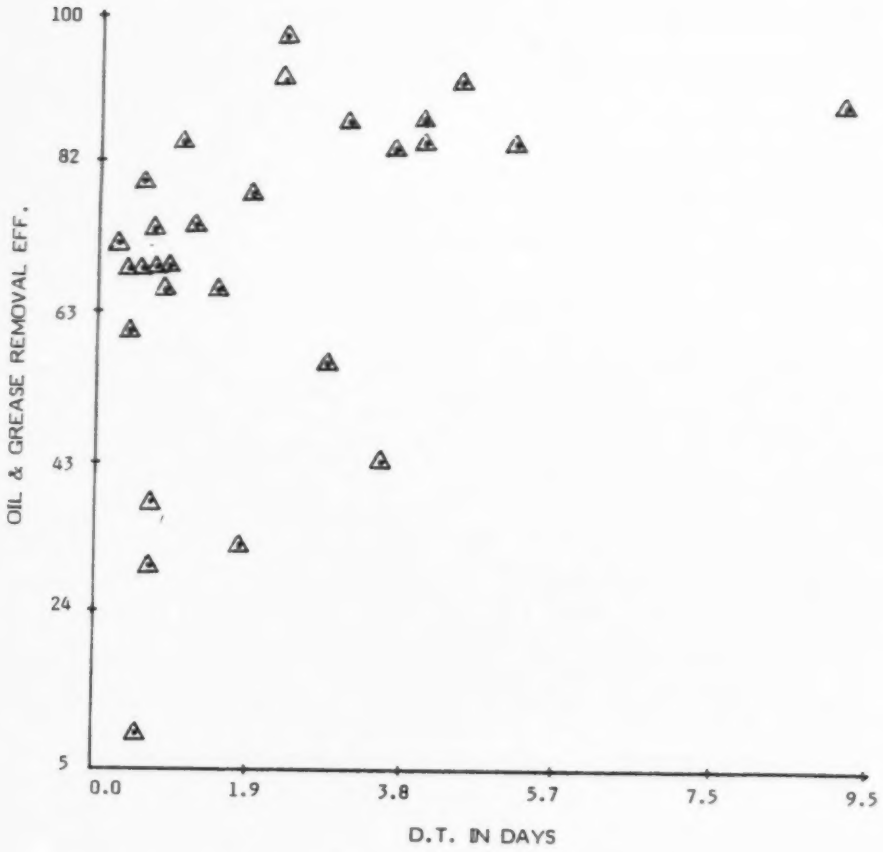
COD REMOVAL EFF. = $31.3 + 55.8\ (DT) - 14.4\ (DT)^2 + 1\ (DT)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-11 EFFECT OF DETENTION TIME ON C.O.D. REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
O & G	68.805	21.264	4.092	96.248	10.000	86.248
D.T.	2.061	2.040	0.393	9.188	0.305	8.883

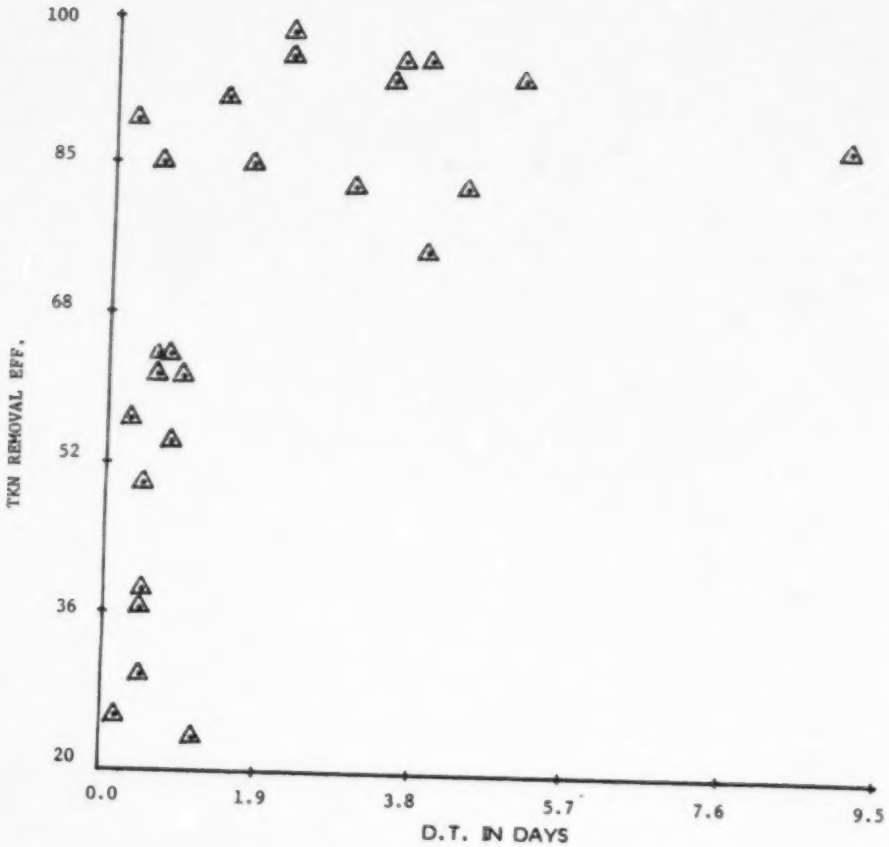
OIL & GREASE REMOVAL EFF. = $53 + 12.3(DT) - 1.4(DT)^2 + 0.06(DT)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-12 EFFECT OF DETENTION TIME ON OIL & GREASE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TKN	69.531	23.489	4.520	97.083	23.810	73.274
D.T.	2.061	2.040	0.393	9.188	0.305	8.883

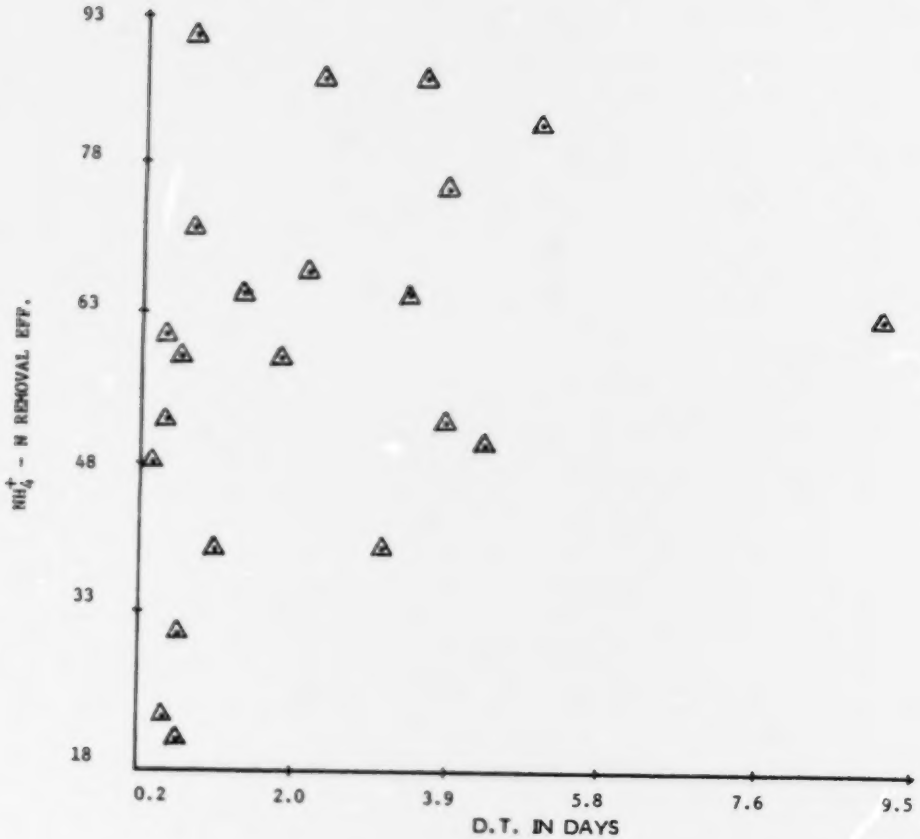
TKN REMOVAL EFF. = $31.3 + 41(D.T.) - 8.6(D.T.)^2 + 0.5(D.T.)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-13 EFFECT OF DETENTION TIME ON TOTAL KJELDAHL NITROGEN REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
NH_4^+-N	58.342	19.404	4.137	89.091	21.622	67.469
D.T.	2.385	2.131	0.454	9.188	0.452	8.736

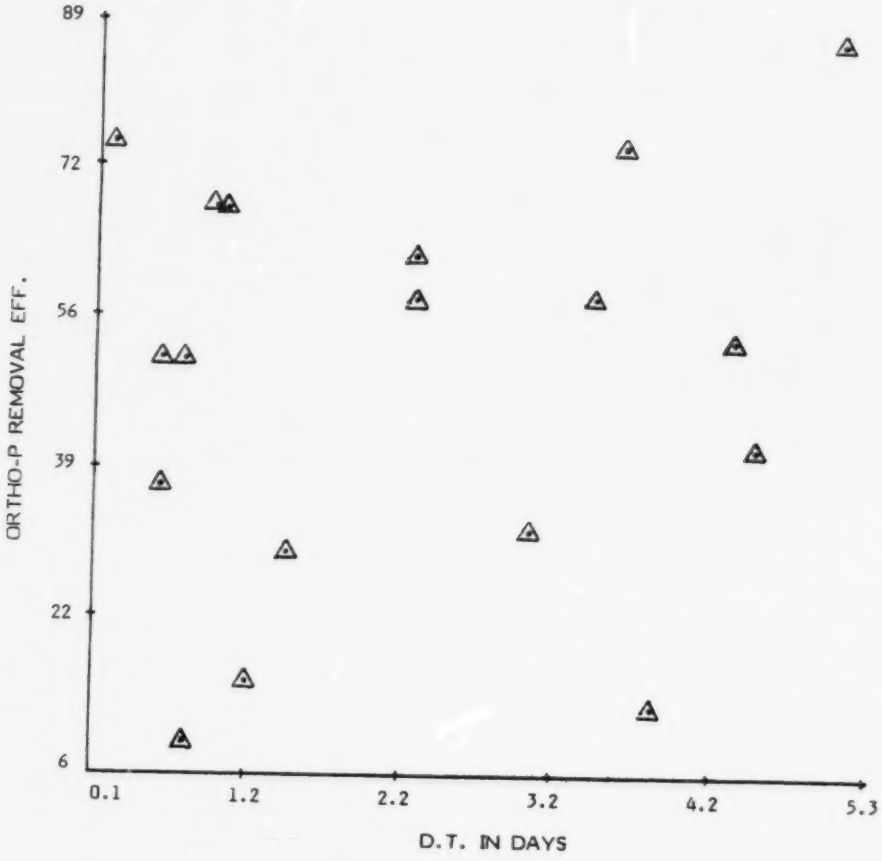
NH_4^+-N REMOVAL EFF. = $35 + 22.9(D.T.) - 4.9(D.T.)^2 + 0.3(D.T.)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-14 EFFECT OF DETENTION TIME ON AMMONIA REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
ORTHO-P	49.261	22.487	5.454	84.687	10.000	74.687
D.T.	2.131	1.560	0.378	5.119	0.305	4.814

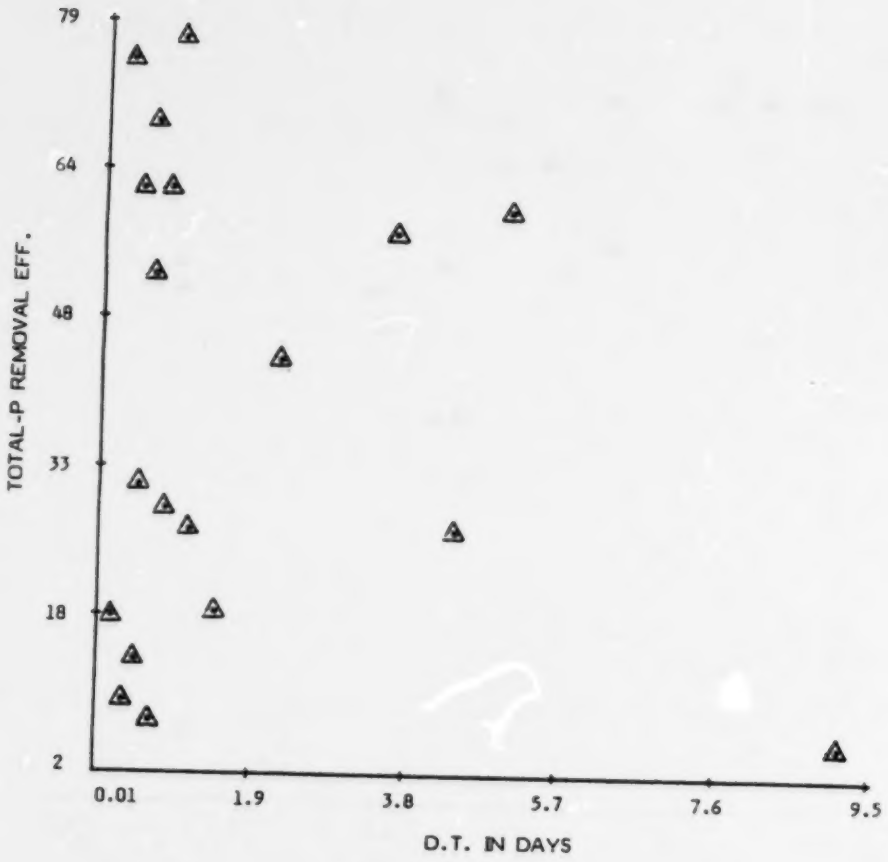
ORTHO-PHOSPHATE REMOVAL EFF. = $53.5 - 8.5(DT) + 0.75(DT)^2 + 0.33(DT)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-15 EFFECT OF DETENTION TIME ON ORTHO-PHOSPHATE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TOTAL-P	40.199	23.536	5.263	75.000	6.250	68.750
D.T.	1.817	2.222	0.497	9.188	0.305	8.883

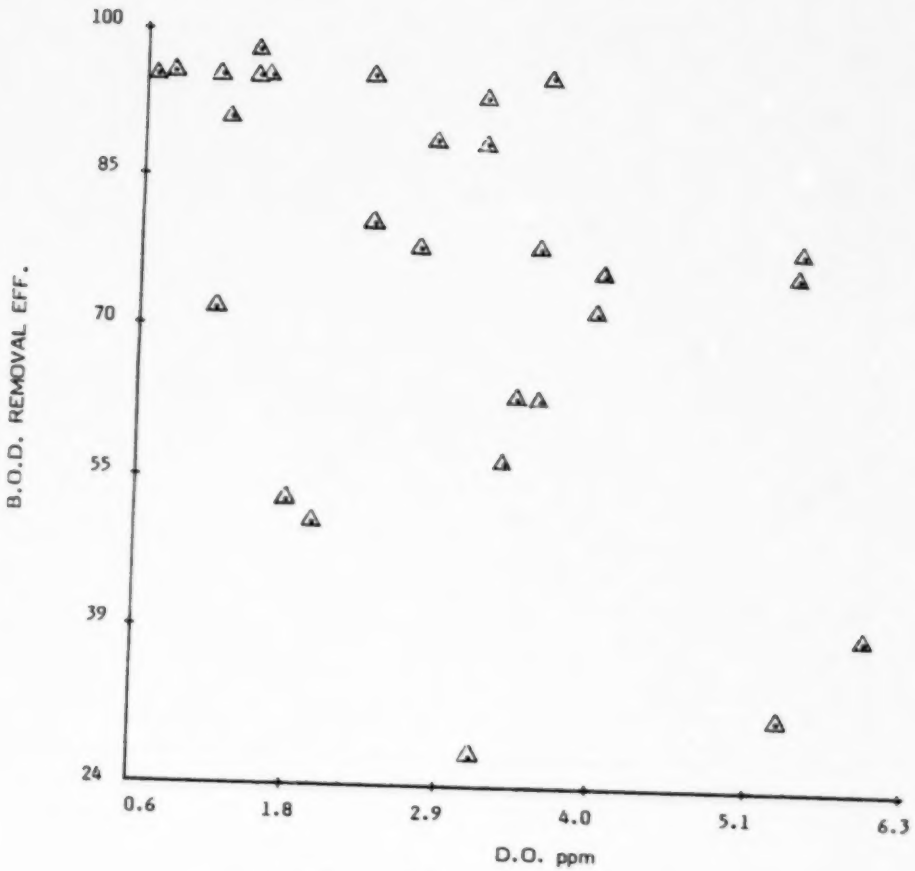
TOTAL-P REMOVAL EFF. = $38.0 + 3.8(D.T.) - 0.065(D.T.)^2 - 0.078(D.T.)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-16EFFECT OF DETENTION TIME ON TOTAL-PHOSPHATE FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DO	2.881	1.550	0.304	6.100	0.800	5.300
BOD	75.899	21.416	4.200	96.311	27.941	68.370

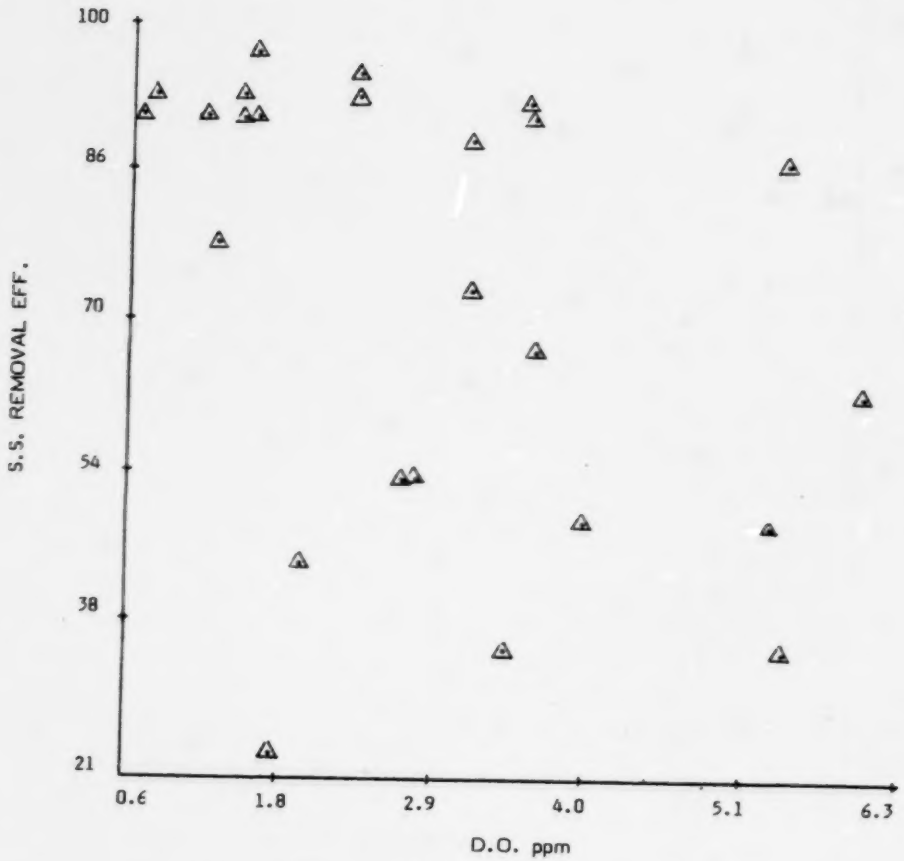
BOD REMOVAL EFF. = $117 - 33.8\,(DO) + 9.2\,(DO)^2 - 0.9\,(DO)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-17 EFFECT OF D.O. ON B.O.D. REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DO	2.862	1.595	0.326	6.100	0.800	5.300
SS	73.027	23.736	4.845	98.690	25.373	73.317

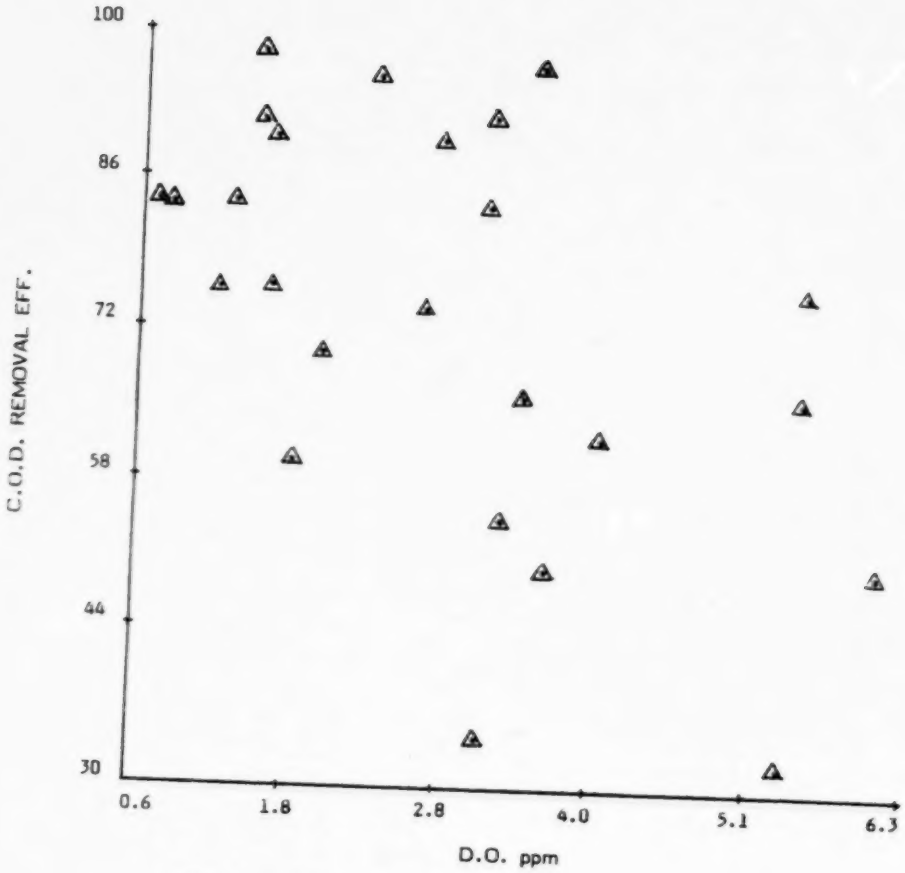
S.S. REMOVAL EFF. = $116 - 30.8(D.O.) + 6.2(D.O.)^2 - 0.4(D.O.)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-18 EFFECT OF D.O. ON S.S. REMOVAL EFFICIENCY FOR PILOT PLANT



	STD. MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
DO	2.833	1.540	0.296	6.100	0.800	5.300
COD	74.564	18.099	3.483	96.804	33.562	63.242

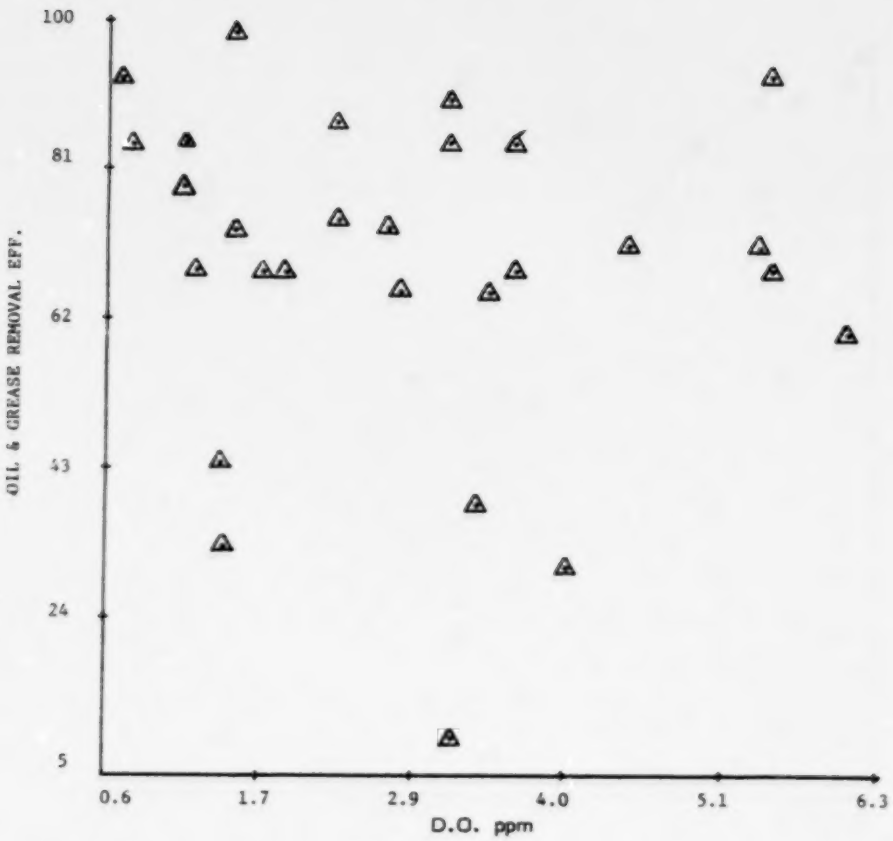
C.O.D. REMOVAL EFF. = $70.6 + 19.1\ (DO) - 8.2\ (DO)^2 + 0.8\ (DO)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-19 EFFECT OF D.O. ON C.O.D. REMOVAL EFFICIENCY FOR PILOT PLANT

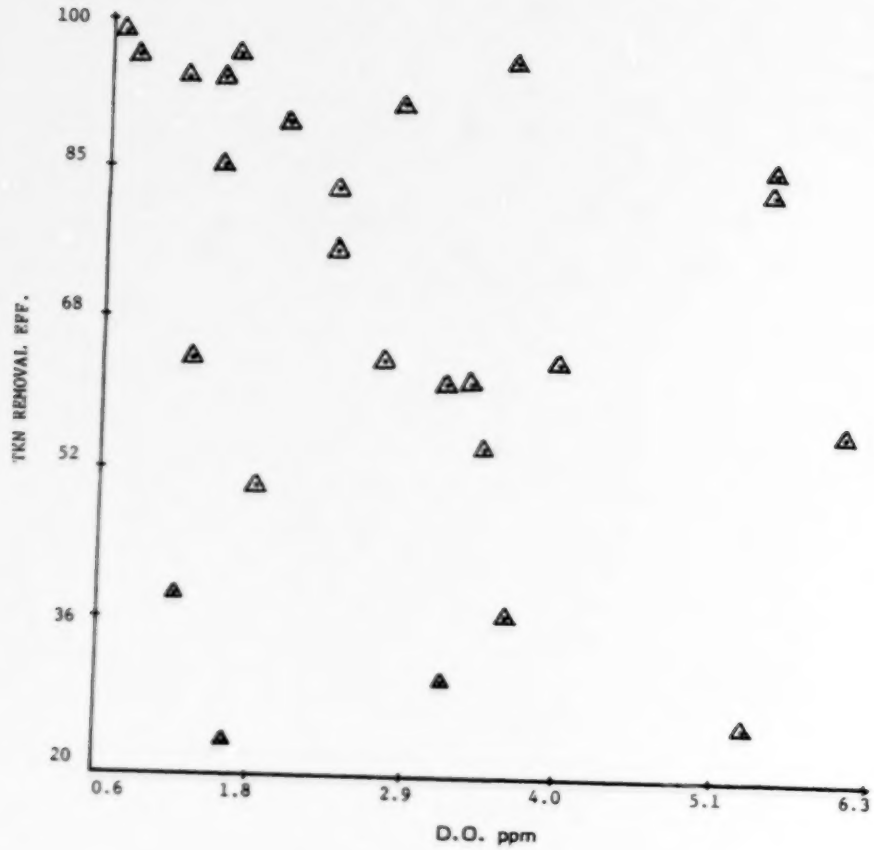


	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
O & G	68.805	21.264	4.092	96.248	10.000	86.248
D.O.	2.833	1.540	0.296	6.100	0.800	5.300

OIL & GREASE REMOVAL EFF. = $95.7 - 21(D.O.) + 3.96(D.O.)^2 - 0.19(D.O.)^3$

OVERFLOW RATE
MEAN = 349 gpd/ft^2
STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-20 EFFECT OF DISSOLVED OXYGEN ON OIL & GREASE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TKN	69.531	23.489	4.520	97.083	23.810	73.274
D.O.	2.833	1.540	0.296	6.100	0.800	5.300

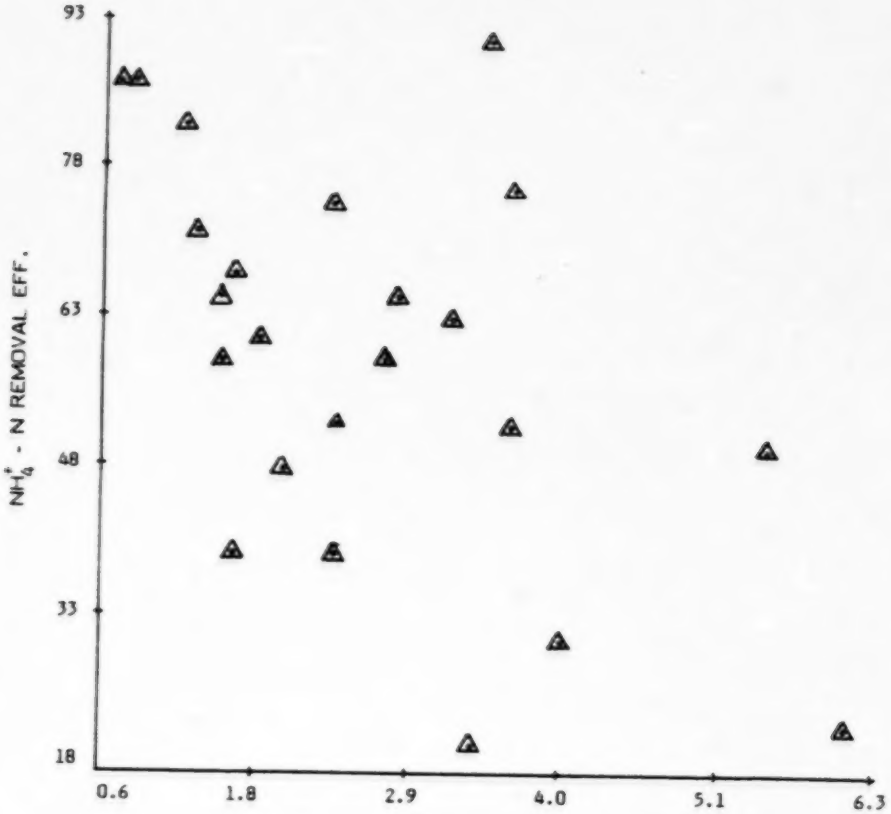
TKN REMOVAL EFF. = $103 - 27(D.O.) + 6.2(D.O.)^2 - 0.5(D.O.)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-21 EFFECT OF DISSOLVED OXYGEN ON TOTAL KJELDAHL NITROGEN REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
NH_4^+ - N	58.342	19.404	4.137	89.091	21.622	67.469
D.O.	2.627	1.432	0.305	6.100	0.800	5.300

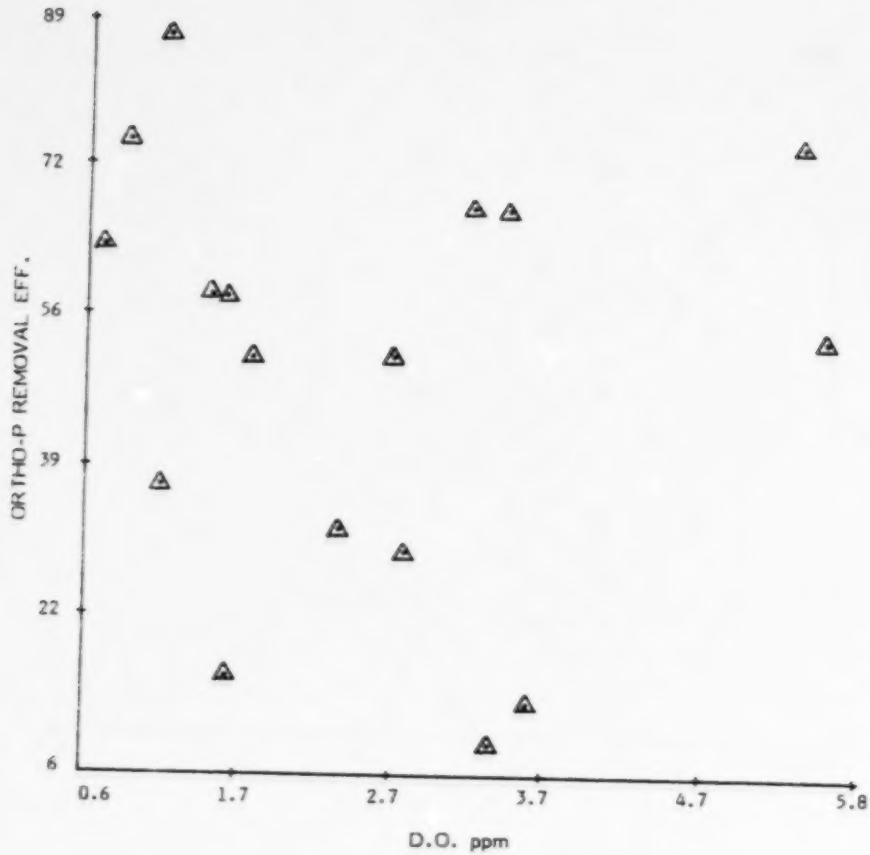
NH_4^+ - N REMOVAL EFF. = $142 - 87.6(DO) + 27(DO)^2 - 2.6(DO)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-22 EFFECT OF DISSOLVED OXYGEN ON AMMONIA REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
ORTHO-P	49.261	22.487	5.454	84.687	10.000	74.687
D.O.	2.553	1.466	0.356	5.600	0.800	4.800

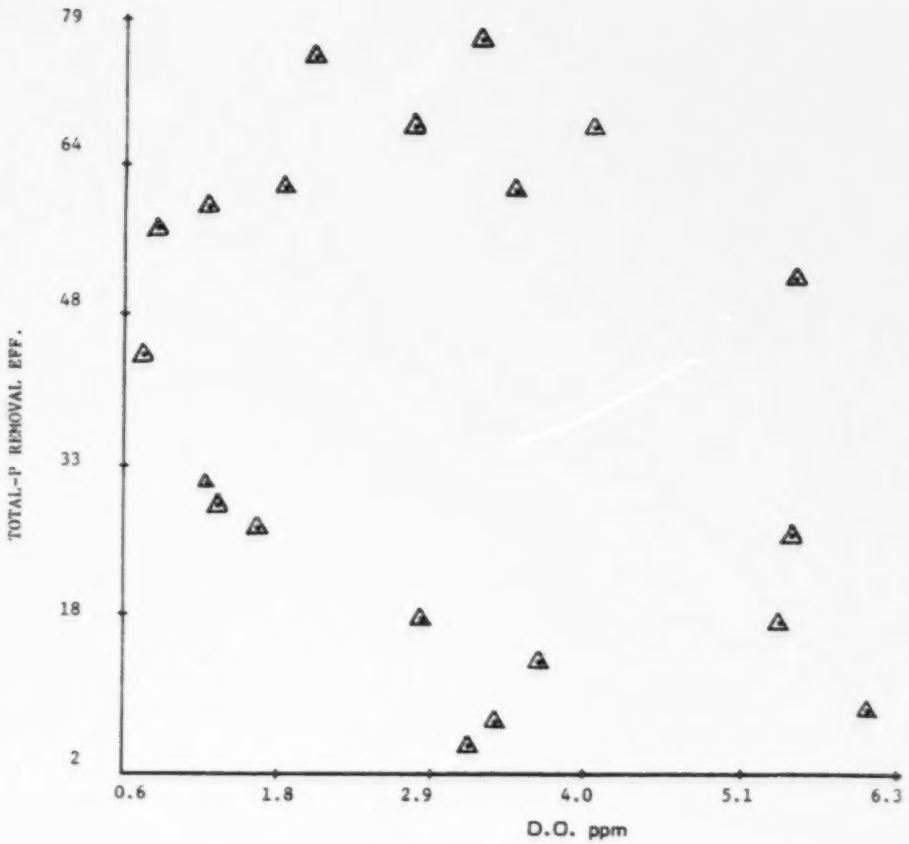
ORTHO-P REMOVAL EFF. = $99.6 - 46.6(DO) + 10.3(DO)^2 - 0.6(DO)^3$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

FIGURE C-23 EFFECT OF DISSOLVED OXYGEN ON ORTHO-PHOSPHATE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TOTAL-P	40.199	23.536	5.263	75.000	6.250	68.750
D.O.	3.010	1.697	0.379	6.100	0.800	5.300

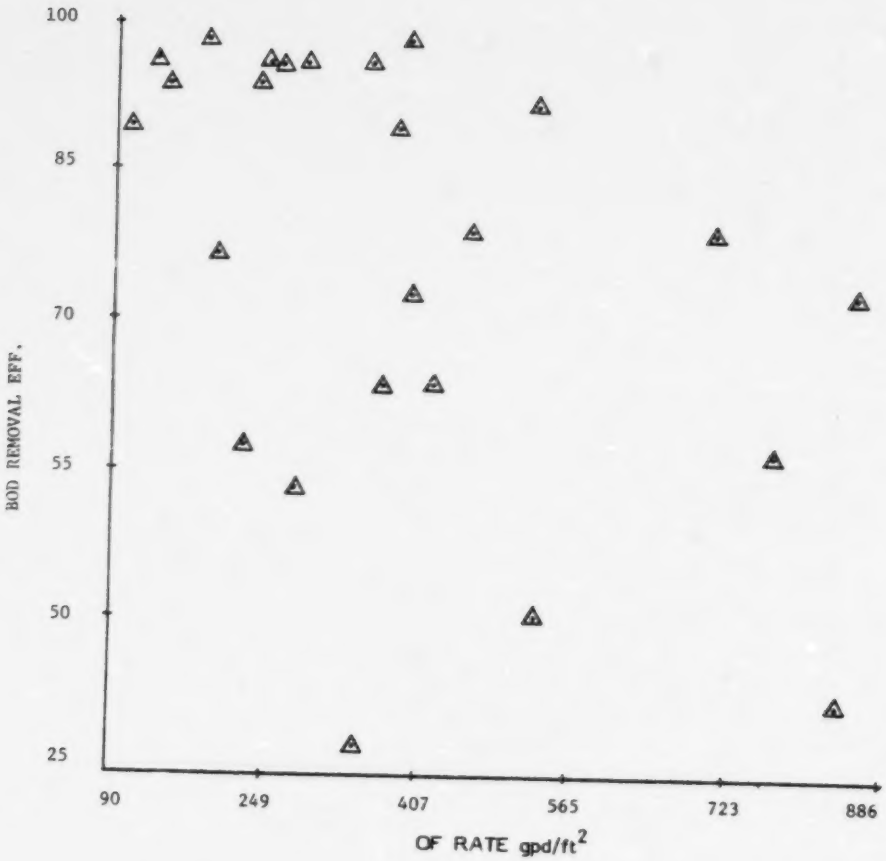
TOTAL-P REMOVAL EFF. = $57 - 14.3(D.O.) + 4.8(D.O.)^{23} - 0.6(D.O.)^{3}$

OVERFLOW RATE

MEAN = 349 gpd/ft^2

STANDARD DEVIATION = 203 gpd/ft^2

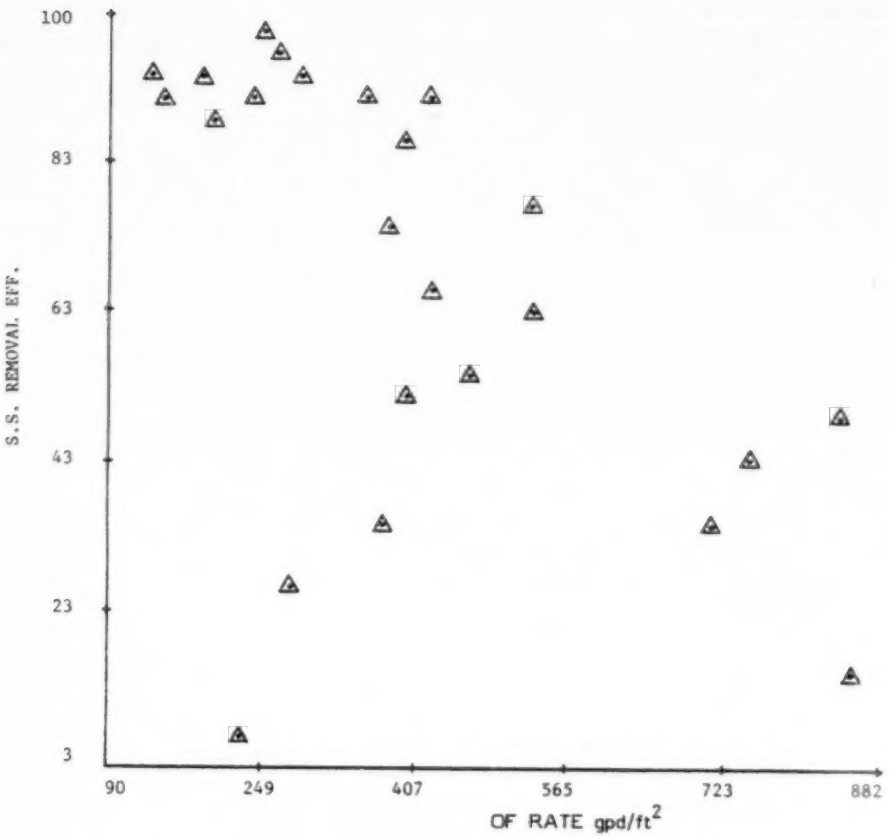
FIGURE C-24 EFFECT OF DISSOLVED OXYGEN ON TOTAL-PHOSPHATE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
B.O.D.	77.198	21.159	3.999	96.311	27.941	68.370
OF RATE	372.783	209.435	39.579	856.799	115.200	741.599

B.O.D. REMOVAL EFF. = $111.5 - 0.2(\text{OF RATE}) + 0.0002(\text{OF RATE})^2 - 1.6 \times 10^{-7}(\text{OF RATE})^3$

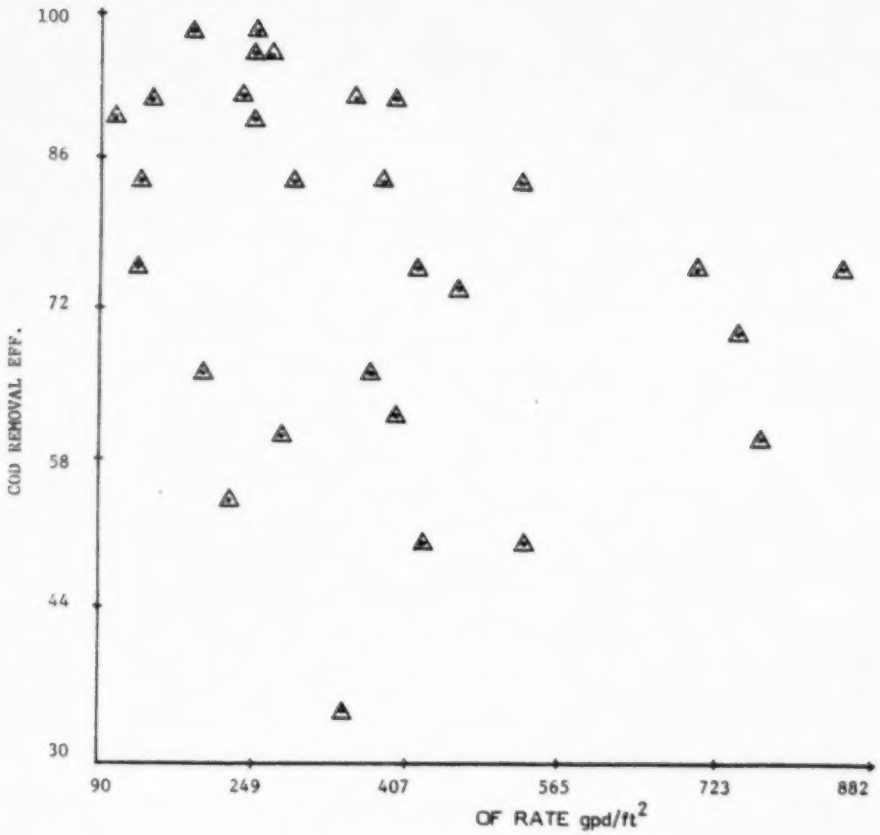
FIGURE C-25 EFFECT OF OVERFLOW RATE ON BIOCHEMICAL OXYGEN DEMAND REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
S.S.	69.777	27.740	5.242	98.690	7.895	90.795
OF RATE	375.654	209.600	39.611	856.799	115.200	741.599

S.S. REMOVAL EFF. = 82.2 - 0.002(OF RATE) - 6.6×10^{-5}(OF RATE)^2

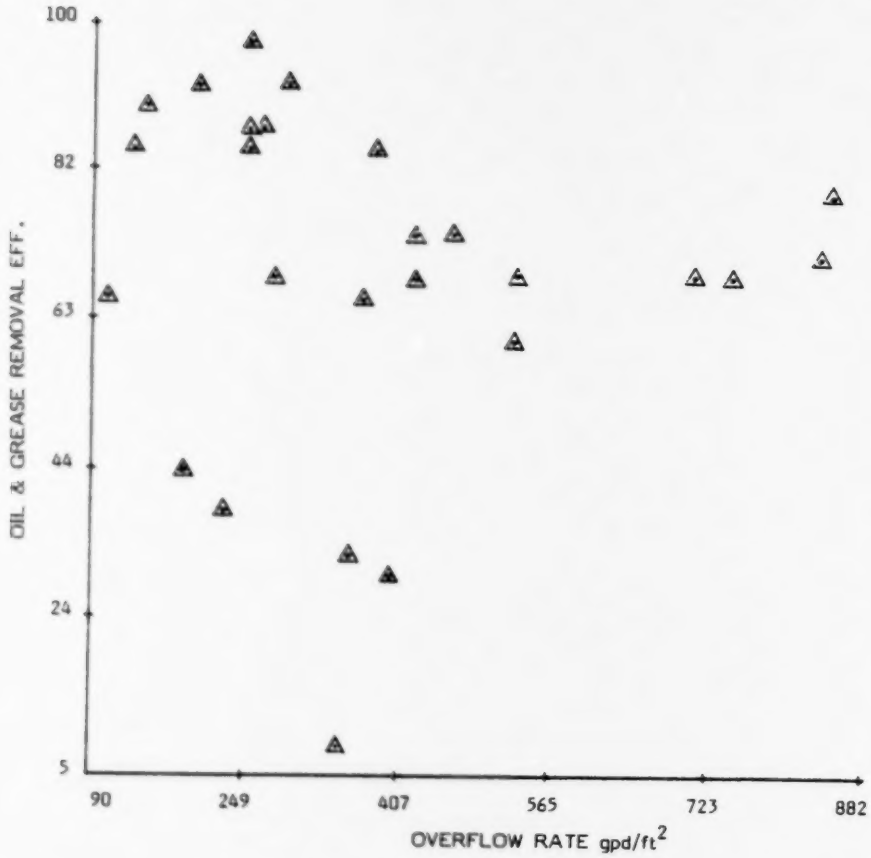
FIGURE C-26 EFFECT OF OVERFLOW RATE ON SUSPENDED SOLIDS REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
COD	75.741	17.987	3.340	96.804	33.562	63.242
OF RATE	374.618	205.898	38.234	856.799	115.200	741.599

COD REMOVAL EFF. = 102 - 0.1(OF RATE) + 0.0002(OF RATE)^2 - 1.2 x 10^{-7}(OF RATE)^3

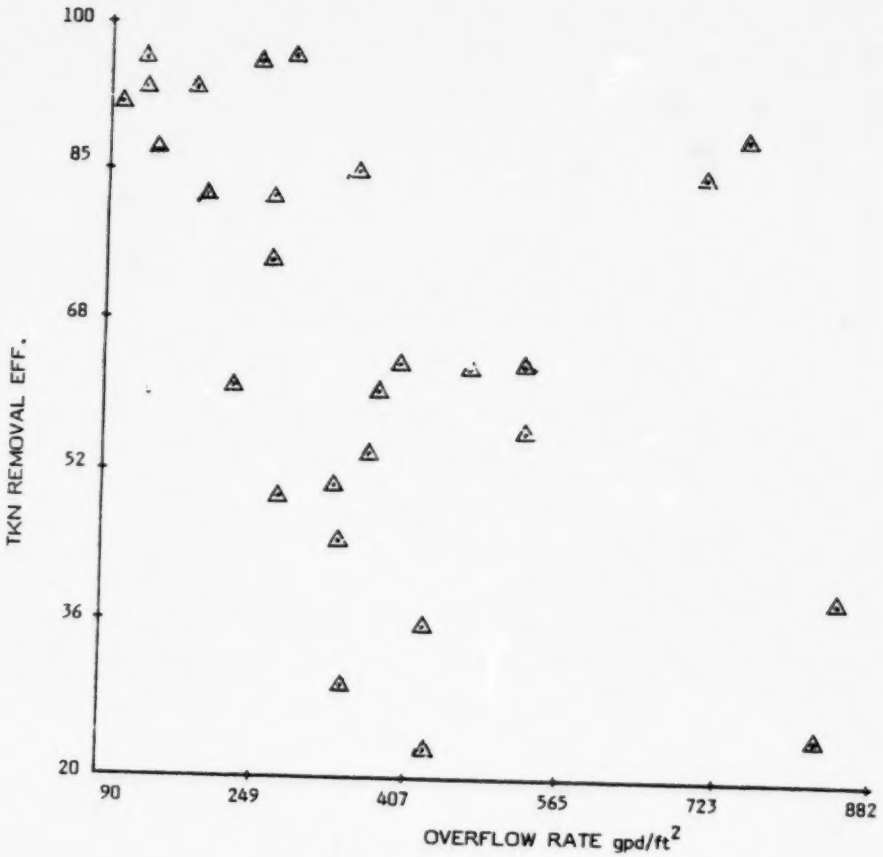
FIGURE C-27 EFFECT OF OVERFLOW RATE ON CHEMICAL OXYGEN DEMAND REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
O & G	68.805	21.264	4.092	96.248	10.000	86.248
OF RATE	378.806	211.893	40.779	856.799	115.200	741.599

$$\text{OIL \& GREASE REMOVAL EFF.} = 96.2 - 0.14(\text{OF RATE}) + 1.5 \times 10^{-4}(\text{OF RATE})^2 - 2 \times 10^{-8}(\text{OF RATE})^3$$

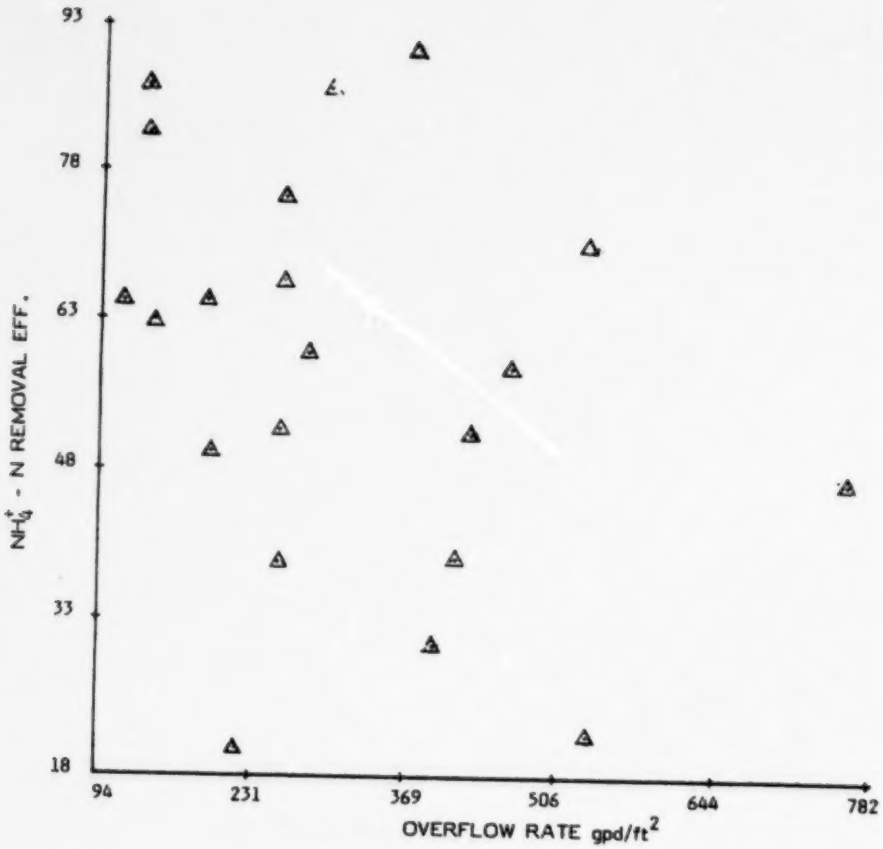
FIGURE C-28 EFFECT OF OVERFLOW RATE ON OIL AND GREASE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TKN	69.531	23.489	4.520	97.083	23.810	73.274
OF RATE	378.806	211.893	40.779	856.799	115.200	741.599

$$\text{TKN REMOVAL EFF.} = 163 - 0.64(\text{OF RATE}) + .3 \times 10^{-4}(\text{OF RATE})^2 - 8.2 \times 10^{-7}(\text{OF RATE})^3$$

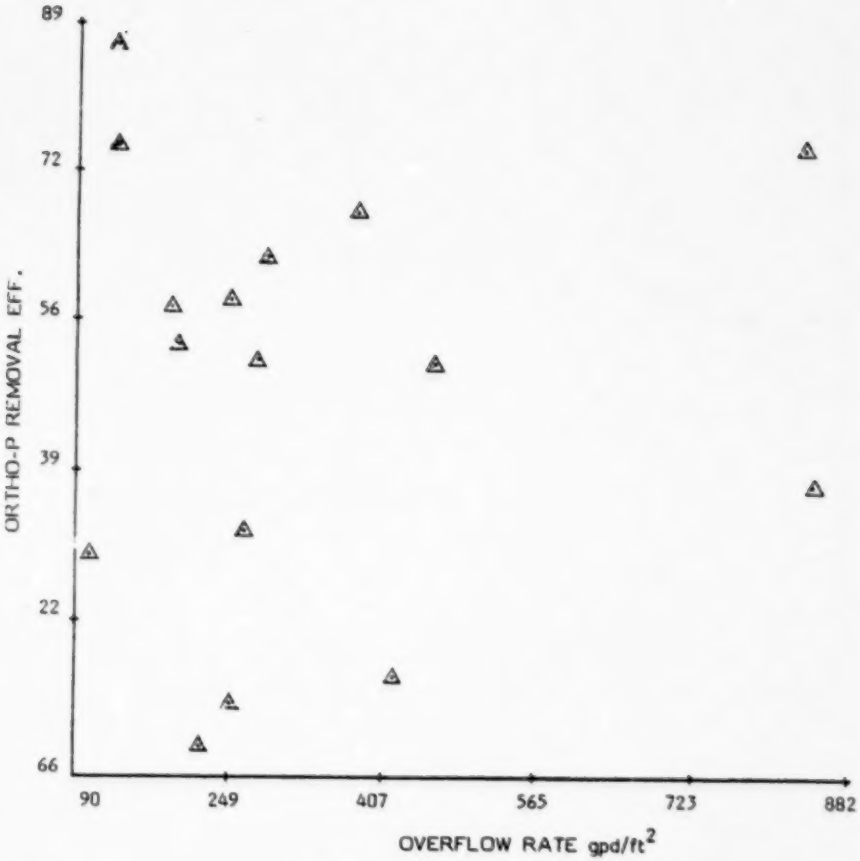
FIGURE C-29 EFFECT OF OVERFLOW RATE ON TOTAL KJELDAHL NITROGEN REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
NH_4^+-N	58.342	19.404	4.137	89.091	21.622	67.469
OF RATE	321.226	158.765	33.849	760.319	115.200	645.119

$$NH_4^+\text{-N REMOVAL EFF.} = 86.2 - 0.16(\text{OF RATE}) + 0.0002(\text{OF RATE})^2 - 1.2 \times 10^{-7}(\text{OF RATE})^3$$

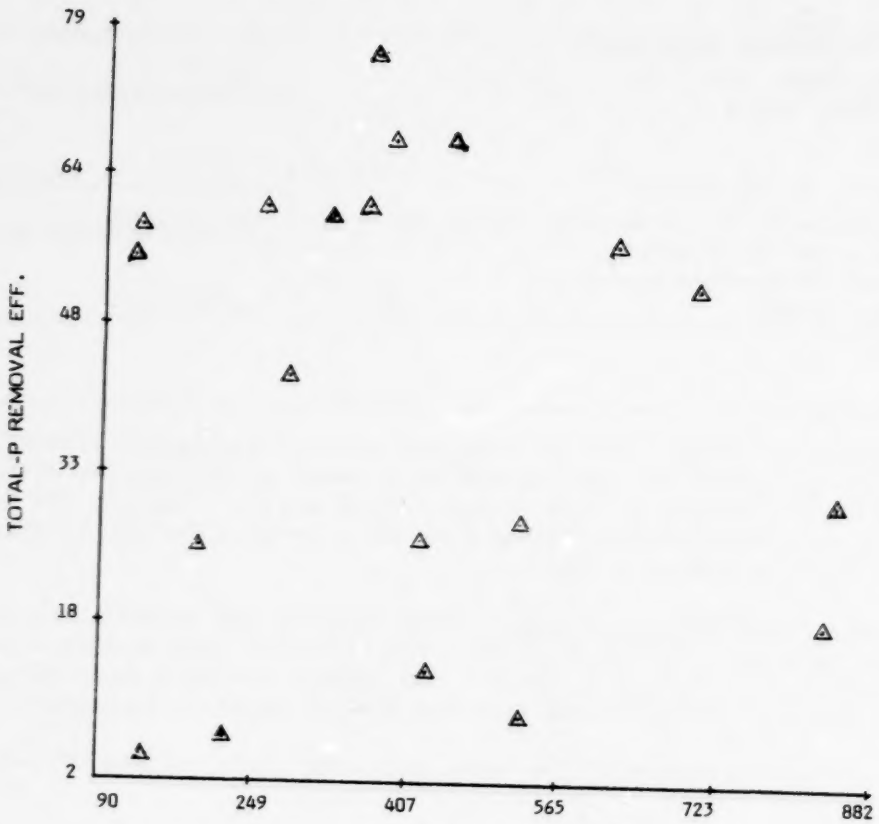
FIGURE C-30 EFFECT OF OVERFLOW RATE ON AMMONIA REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
ORTHO-P	49.261	22.487	5.454	84.687	10.000	74.687
OF RATE	337.371	217.594	52.774	856.799	115.200	741.599

ORTHO-P REMOVAL EFF. = $95.3 - 0.4(\text{OF RATE}) + 9.5 \times 10^{-4}(\text{OF RATE})^2 - 6.3 \times 10^{-7}(\text{OF RATE})^3$

FIGURE C-31 EFFECT OF OVERFLOW RATE ON ORTHO-PHOSPHATE REMOVAL EFFICIENCY FOR PILOT PLANT



	MEAN	STD. DEV.	STD. ERROR	MAX.	MIN.	RANGE
TOTAL-P	40.199	23.536	5.263	75.000	6.250	68.750
OF RATE	414.186	235.131	52.577	856.799	115.200	741.599

TOTAL-P REMOVAL EFF. = 24.6 + 0.064(OF RATE) - 1.1 x 10^{-5}(OF RATE)^2

FIGURE C-32 EFFECT OF OVERFLOW RATE ON TOTAL PHOSPHATE REMOVAL EFFICIENCY FOR PILOT PLANT